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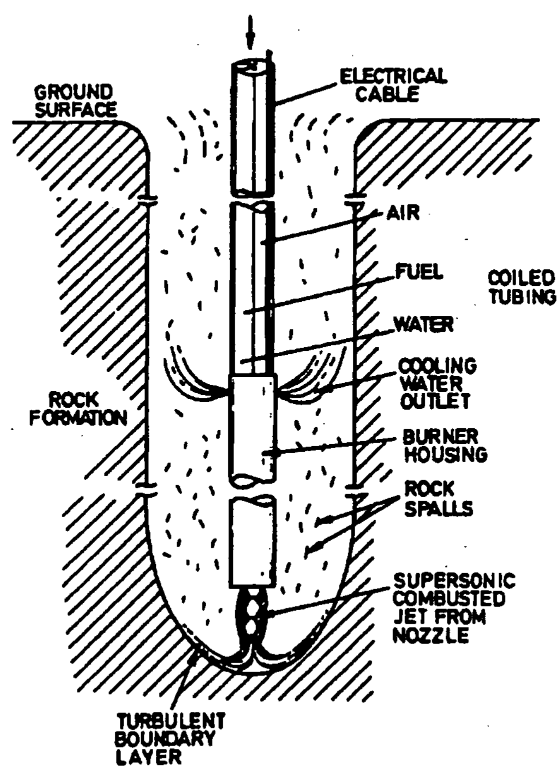
(54) Title: IMPROVEMENTS IN OR RELATING TO DRILLING WITH GAS LIQUID SWIRL GENERATOR HYDROCYCLONE SEPARATION COMBUSTION THERMAL JET SPALLATION

(57) Abstract

A high velocity 3 phase mixture is pumped down a drill string to a vortex swirl generator/hydrocyclone for 2 phase separation flow into a twin vortex combustion chamber manifold that swirls the air in and around the fuel and water mixture droplets (atomise) producing instant exothermic heat of combustion thereby producing a super-critical thermal spallation jet flow; with surface control of the water to fuel (kerosene) content allows temperature control between 400 °C and 1,800 °C with additional abrasive particles if required, axial pulse jets are also optional for further erosion to the rock face, allowing the spalling of all rocks with high strength to low ductile transformation temperatures. The spallation drilling system makes possible drilling of well bores to allow the use of steam drive and alternating steam injection within oil reservoirs and electrical power generation which are able to use super-critical HDR principles with water temperatures above super-critical 374 °C and critical pressure of 3,204 psi for expansion back to lower pressure with high quality steam.



IMPROVEMENTS IN OR RELATING TO DRILLING WITH GAS LIQUID SWIRL GENERATOR HYDROCYCLONE SEPARATION COMBUSTION THERMAL JET SPALLATION

Background of invention and Description of Prior Art

For many years there have been drilling or boring into the earth's crust for hydrocarbons or minerals through sedimentary rocks or geothermal igneous and metamorphic rocks for creating hydrothermal or manmade hot dry rock (HDR) this has been done in order to a fracture reservoirs for water injection and extraction of high pressure hot water/steam, over the years these wells have been drilled with bits that Howard R. Hughes Snr. first invented in 1908 for rotary drilling with two and three roller cone cutters that revolutionised the drilling industry which today permits holes to be drilled to deeper than 30,000 feet, some bits have cutter teeth for softer formations with harder formations the use of tungsten carbide inserts are used on plain roller cones, other types of bits developed over the years for hard abrasive formations have used industrial diamonds or PDC inserts (Polycrystalline Diamond Compacts) set in a matrix on flattened cones the same diameter as the well bore, with grooves in their surface for the drilling fluid pathways, some such bits are hollow. These are coring bits, which allow, the cutting of a solid core intact, to be brought to the surface. Typically all bits have jets between the rollers or grooves from which the drilling fluid/mud exits, cleaning chips instantly from the bottom of the well. In the early days in soft formations the velocity

of the fluid through the jets help drill faster. In soft formations the jet's fluid velocity may wash out the well bore. Other developments over the last few years have been with the inclusion of high pressure jet drilling, or jet nozzles that allows destructive fluid forces to chip and fracture the well bore face by cavitation of the fluid or pulse jet, water hammer destructive forces between the drill bit and the well bore face prior to mechanical action of the rotary drill bit.

Either by the rotary action of the drill string or with the use of coiled tubing with rotary drilling mud motors also used for directional drilling but with limitations as to depth and temperature, additionally there is a vast amount of time wasted in tripping in and out of the well with the drill string. One major problem is the high torque and tension loads on the drill string or coiled tubing and the amount of time and vast expense retrieving broken drill string components within the well bore, fishing operations. The present invention relates to linear drilling technology by a non mechanical cutting drilling system that requires no rotation of the drill string or a rotary drilling mud motor. The invention consists of an orientation unit, trajectory control unit, controlled by fluid pulse telemetry or electrical control, to the hydraulic system together with a high speed rotary centrifuge, or cyclone or stationary vortex, swirl generator & hydrocyclone, gas liquid separator and penetrator head or combination of the same for (Multi-component) two stage separation down hole with combustion jet chambers for single or multi (Thermal) jet spallation drilling, without any mechanical drilling action between the penetrator drilling head and the well bore interface allows for true linear drilling. Allowing for ultra-fast drilling rates in soft to ultra-hard formations, even in high temperature wells which in turn allow for considerable cost savings. The future for spallation drilling is clearly strong, exponential dependence of cost on depth are centred on penetration rates in harder rock located at greater depths and the amount of wear on drilling tools and drill string tripping times, required to replace drilling bits and tools with spallations linear drilling's fast penetration rates. This changes the exponential relationship between cost and depth.

The search for a more efficient energy transfer, drilling and boring system has resulted in a number of recent inventions. The development of hydraulic erosion jetting has over the years been the subject of increased interest. This design which includes more efficient energy conversion to the work surface and ideal working medium, water, which is in great abundance and economically expendable along air and kerosine, for thermal spallation.

Hydraulic erosion and flame jet spallation of earth formations is a technology that has been reported in numerous technical and patent publications. The erosion takes place by employing various failure mechanisms of the surface induced by action of the liquid jet or flame jet. The type of failure mechanisms that have been reported include:

A. Failure of porous rock due to stress induced through liquid filled pore spaces of the rock brought about by impacting the liquid contained in the pore space.

B. Formation failure by crack propagation and or extension due to hydraulic fracture forces occurring when a liquid filled fracture is forced to close after an initial mechanical force is released.

C. Liquid jet droplet impingement that erodes the cementation between formation grains thereby loosening and dislodging the harder formation grains, this technique is known as soft erosion and is the mechanism present when eroding formations where the impinging jet stagnation pressures do not exceed the threshold pressure required to fracture the rock and thereby force large scale permeability in-situ formation.

D. Formation failure by droplet impingement, known as hard erosion, that fracture the rock grains and cementation by exceeding the threshold pressure necessary to fracture the formation grains and force large scale permeability by breaking down the individual grains away from the formation.

E. Formation failure by liquid jet induced pressure reversals allow the in-situ formation pore pressures to force tensile failure of cementation holding rock grains together.

F. Formation failure by, cavitation within the fluid, using an apparatus for forming a high velocity swirling liquid cutting jet through a PDC wear button for stress induced in the

abrasion, pressure reversal, cavitation and fracture propagation as the jet continues to flow along the kerf formed by the jet, by phase change. that exhibits multiple erosive interactions which collectively erode the in-situ formation.

G. Thermal spallation drilling is a process with great potential for reducing the costs of drilling holes and mining shafts and tunnels in very hard and ductile rocks. Industry has used a similar process to this to drill blast holes for emplacing explosives and to quarry granite. The drilling industry used the best tungsten-carbide insert tricone bits and a conventional rotary drilling system to drill a 9-5/8-in-diameter hole in solid granite. Maximum drilling rates of 12 ft/hr were obtained. Concurrently, at Conway New Hampshire Browning Engineering Company (BEC), working on contract to Los Alamos produced by the spallation process an 8 to 10 in, diameter hole 1086 ft deep in solid competent granite at an average advance rate of 51.7 ft/hr and at rates in excess of 100 ft/hr near the end of the run. The spallation drilling was performed with a newly designed flame jet burner and a simple rig, which supported the burner on flexible hoses and was operated by a two man crew.

Because of the low thermal conductivity of many hard rocks, rapid heating produces a thin surface layer in which the temperatures attain high values, Thermal expansion of this surface layer is constrained by the remainder of the still cool rock, and as the stresses within the surface rock become high enough it breaks away from cooler rock behind it flies or falls off as a thin flake called a spall. Then the next, newly exposed surface is heated and the process continues. This process is the basis of spallation drilling. The hot gases from a jet burner provide the heat for spallation to occur and their high velocity provides a scouring action that transfers heat to the rock and removes the spalls as rapidly as they form. A wood fire placed against a rock face may have been the first non manual mining method used by man as well as the first use of spallation. However, the system remained almost entirely undeveloped until, in the 1940's the Union Carbide (UC) began developing spallation for use in mining taconite ore, which is presently the chief source of iron in the United States. In this work UC developed a jet-piercing tool that burned fuel oil with oxygen to produce spallation

and also contained mechanical cutters to remove rock that was not amenable to spallation. The UC jet-piercing machines have since produced about 40 million feet of shallow blast holes used for emplacing explosives in the taconite mines. It was found that hole diameters could be increased by merely reducing the advance rate of the burners and that existing holes could be enlarged by making another pass through the hole with the same burner.

BEC has developed a hand-held spallation burner to cut slots in granite. The tool has been used for 50 years and is now standard equipment for quarrying granite throughout the world. This burner. which resembles a small jet engine with its jet pointed downward, is the forerunner of the flame jet burner used to make the 1,100 ft hole at Conway, New Hampshire. It uses no. 2 fuel oil, which is burned with compressed air and ignited by a spark plug. The system used water to cool the burner and the exhaust gases. These gases along with the steam produced from the cooling water, blow the spalls from the hole. Our method of spallation allow for ultra-deep drilling in all types of formations with super-critical fluid, flowing past the rock surface to spall the well bore super-critical combustion thermal jet spallation, with gas/liquid generator and hydrocyclone separation system, with temperature variable control from 400°C to 1,800°C (or 2,100°C without water with the fuel).

Gas Liquid Swirl Generator Hydrocyclone Separation Combustion Thermal Jet Spallation Drilling.

Summary of the First Aspect of the invention

Drilling Excavation & Mining Technologies

The aspect of the invention will be described which allows spallation of all types of rocks by thermal (jet) spallation rock structures have varying plastic deformation hardness and ductility and are subject to a wide range of spalling temperatures. The wide range of thermal combustion gas/steam temperatures obtainable with my invention of atomising the

water with the kerosine for a better burn rate, produces a super-critical gas/steam thermal spallation jet that allows, temperatures of between 400°C to 1,800°C (2,300°C with coiled tubing) and the swirling (cyclone effect) of the spalling gases, on the rock face this allows spallation, without melting the rock. This was never possible with the systems developed and manufactured by Browning Engineering, Union Carbide, Los Alamos National Laboratory, The New Mexico Institute of Mining and Technology the Massachusetts Institute of Technology and Maurer Engineering. Also allow the use of combustion jet spallation from a penetrator drilling head or in combination with a rotary centrifuge fitted to a trajectory control unit, the top of the trajectory control sub is fitted to the high speed rotary centrifuge or fixed vortex/hydrocyclone drilling head that houses the vortex chambers either singular in height or multi stacked with swirl generator for this high density low fluid velocity ultra high vortex separation, fitted with tangential flow ports, the centrifugal unit is rotated either by single or multiple epitrochoidal in-rotor motor, turbine motor vane type motor or centrifugal type motor for use in high temperature wells. The method used combustion jet spallation to penetrate into rock, ultra fast through the surface, injection of water, fuel and compressed air, together at prescribed amounts from the surface. Tests have shown that a pressurised flow of water through the drill string can transport the required amounts of fuel, air as a multiphase mixture to support combustion capable of thermally spalling rock at ultra fast rates will also prevent combustion within the drill string, on its way to the vortex separation system by the dual action of centrifugal and vortex swirls, where the centripetal forces inside the vortex chambers two stage separation of the concentrated fuel and compressed air recombination that permits oxidation whose exothermic heat of combustion will produce a mixture of super critical water nitrogen and carbon dioxide for expansion as a subsonic jet. This allows for the water content within the fuel to be from zero to 30% to be mixed with the fuel by valve control on the outlet side of the stationary or rotary vortex chambers or centrifuge rotating around a central bearing assembly in the centrifuge, rotating at speeds over 300 rpm to cause centrifuging. The stationary system uses a swirl generator and

hydrocyclone separation unit whereby the water is injected into the fuel to increase combustion. The water droplets atomise the fuel, allowing for a better burn within the combustion chamber, this allows combustion chamber temperatures from 400°C to 1,800°C by surface control of the fuel water concentration. The combustion jet chambers' air and fuel are exothermal, that produces an ultra-high velocity (supersonic) or (subsonic) super-critical thermal jet, by pressure adjustment across the nozzle to a level beyond the critical ratio that induces thermal high energy, reaction stress at the rock interface, this causes disintegration particles, spallation and the small chips and fragments of the rock, that are formed will be removed by velocity from the well bore by the exiting combustion gases/low density steam, with the use of circulation water flow exiting through the annulus allowing sufficient kinetic energy to overcome pressure losses and will provide the required lifting force to remove the spalls. Rock failure can also be by fluid side peripheral pulse/jets water hammer effect along with spallation these events are repeated and instabilities are amplified alternating loads (absolute formation stress) and heat transfer processes up to 1,800°C and over combustion flame jet chamber pressure equals normal hydrostatic plus 500 psi, temperature at 1,800°C at 50,000 foot depth and 18,000 Hst (W/m2K) see Fig 41 allowing high destructive erosive rock spallation. The cooling water exits the co-axial orifice jets to control gases spalling the well bore diameter.

Compressed air and fuel are injected into the flow of water or drilling fluid for pre-mixing. From the rig pumps the mixture is transported as bubbles in the water phase the two phase fluid is equal to hydrostatic pressure even in deep well bores 50,000' the solubility of nitrogen and oxygen in the water phase will be very low, about 5% by weight, the density of the gases relative to liquid water will be a factor of 0.1 - 0.5 lower for easy separation by vortex/hydrocyclone or centrifuge. Kerosene allows a second stage separation from the water phase down hole storage of fuel and compressed air if required allows injection from the surface of much higher concentrations and re-concentrated fuel/water content of up to 30% still allows exothermic combustion with compressed air.

The effects of rock mechanical behaviour in thermal spallation is by the control of combustion chamber temperature from 400°C to 1,800°C by electrical valve control within the special triple vortex jet manifold, the outlet side of the vortex fuel/water mixture exit orifice. allowing exothermic heat of combustion in the chamber, this super-critical jet flow allows for all types of formations to be penetrated from igneous (granite) (basalt) metamorphic crystalline rocks, dolomite, sandstone. limestone, phyllites, taconite, shale, permafrost, etc. As HDR well costs decrease, a larger fraction of the earth's available resource becomes commercially viable due to spallation drilling. In addition. other fields of interest including tunnelling for transportation, cavity formation for energy storage, mining, deep-well drilling for waste storage and treatment, and oil and gas drilling in the overthrust belt would benefit from a rapid, inexpensive method for penetrating through crystalline rock Heat flux applied to the rock, the outer edges expand first, and a thin layer/chip of rock (called a spall) is broken off. It breaks off in a tensile mode which has a much lower energy requirement than compression mode. High temperature spallation drilling works best in rocks with high quartz content. such as granite, quartzite and some sandstones. These rocks are able to build up the required compressive stresses, under rapid heating conditions, before stress relieving mechanisms such as softening or melting occur. More typically encountered rocks such as limestone and shale, which are found in oil and gas well drilling "soft" rocks by producing a periodically heated surface from 400°C upwards, lower temperature limestone is spalled at rapid rates. Fluid flow and heat transfer process are important in drilling and quarrying for penetration rate and borehole geometry. Operating variables such as flame (thermal) temperature, jet velocity, stand off distance and the thermo-physical properties of the rock.

Unlike other methods tested in the past, my invention uses compressed air and kerosine which is injected into the water (drilling fluid) and transported as bubbles in the water phase, to be separated out in two phases by power fluidics vortex, gas liquid swirl generator and a hydrocyclone fluid separation system. The recombination of the separated compressed air

and concentrated kerosine/water allows the water droplets to atomise the fuel allowing for a better burn within the combustion chamber, this will then permit oxidisation within the combustion jet chamber where the exothermic heat of combustion will produce a mixture of hot super critical water/steam, nitrogen and carbon dioxide which is expanded as a subsonic jet. This jet flow produces stagnation heat fluxes of up to 20Mw/tm^2. The heat fluxes are so high that the post combustion injection of water will allow lower temperature thermal jets between 400°C and 1 ,800°C which will spall all types of rock. The system can then be used for high strength to low brittle rock with ductile transformation temperatures. With the use of supercritical hot dense fluid flowing past the rock surface to be spalled, this will produce a superior spalling action. Heat flux determines the onset temperature of spallation and the subsequent penetration rates. Spalling a wide range of rocks is obtainable by producing a lower temperature flame with a very high gas velocity. This is obtainable by atomising water in with the kerosine to produce a range of various super-critical combustion temperatures at increased velocities, this is further aided by the swirling pulse mechanism produced by the nozzle and combustion chamber design allowing for the low density of super-critical fluid flow that gives twice-the gas jet volume to be moved (swirled) around on the surface of the rock so that the rock therefore does not reach melting temperature. This method would enable the spallation head to remain stationary without rotation.

The very large mass of water/drilling fluid to combustion products allows lower temperature increases in the mixed water exiting upwards through the annulus this carries sufficient kinetic energy to overcome pressure losses and provide the required lifting force to return the spalls to the surface. Pressure adjustments can also be made to intensify the pressure drop across the combustion jet nozzle to a level beyond the critical ratio; thus producing a supersonic flame jet flow.

Increasing the density of the drilling fluid (mixture) in the empty wellbore will increase the depth in which instability in the bore occurs Super-critical water jets (water hammer) and acoustic vibration will also increase drilling speeds that will reach hundreds of metres per

hour. This is due to increased heat transfer with increasing stresses in the bore, from overburden loading.

The use of thermal combustion spallation drilling in oil and gas 'veils, with drill pipe or coiled tubing drilling unit, for under balanced drilling, produces low density products of combustion nitrogen and (CO_2) carbon dioxide and super-critical steam, the inert, non-reactive nature of the gaseous nitrogen and CO_2 is such that it will not support combustion. Because of this there is no risk of downhole fires or explosions. Other major advantages that cuts drilling time to the minimum is due to the fast rates of penetration, drilling any size of bole, with coiled tubing or drill pipe. Medium and short radius well bores are developed with ease, due to the trajectory directional control units flexibility in spallation drillings. The well bore size compared to the spallation head size, allows continuous high or low angle build rates resulting in reduced frictional drag, producing a cautionary curve, allowing smooth inclination, no doglegs or key seating.

The limit to the rate of penetration will be in tile handling of the drill string, the ideal use would be coiled tubing, with less tripping time, making this the preferred drilling process. With multi tubing string, it would enable a gas lift removal of the cooled combustion products and rock spalls within the drill tubing annulus which creates lift velocity.

This high density "submerged" flame jet's spallation system shows a very strong depth dependence, -see Fig 41 Heat transfer coefficients result from increasing heat transfer stresses in the well bore from over burden loading allowing significant penetration rates to make this a true linear drilling method particularly when used in conjunction with a downhole tractor pulling system for ultra long reach horizontal drilling, and micro tunnelling. Fig 55 shows actual and estimated drilling speed.

The drilling combustion head of the penetrator drilling assembly can be rotated by an orientation unit, fig 18, above the trajectory control unit as shown in fig 14 of Patent Application PCT/GB 94/00515 and others with a modification by removal of output thrust shaft item 5 and modification to output thrust shaft item 27 and bottom stabiliser sleeve and

bearing housing retaining sub by the fitment of the epitrochoidal tri-rotor motor or turbine to drive the centrifuge/multi-vortex penetrator jet unit. This system allows ultra fast/deep drilling with either drill pipe or coiled tubing to depths of 50,000 feet or deeper, the size of the well bores will be controlled by the size of the penetrator drilling head, with no problems of stuck pipe or drill string drag within the well bore. Depending on the type of fuel used for combustion an ignition (spark plug) can also be used (not shown).

Worldrill's patented new true linear drilling process is a new rock drilling technology that uses thermal combustion-jet spallation and super-critical water erosion/heat flux to penetrate rock. The thermal-jet induces thermal stress at the rock face. Spallation occurs, and the small rock chips that form are blown out of the well by the exiting combustion gases. Tests emphasise that rock-failure and communication mechanisms during drilling, is due to fluid hydraulic erosion and heat transfer process that affect rock mechanical behaviour in thermal spallation applications. With a self-guided trajectory control system that will help optimise this true linear drilling process. For ultra deep drilling by the use of hydrodynamic forces, for fluid separation, power fluidics is based on the physics of centrifugal force, free vortex action in an enclosed space.

a) The spallation burner does not touch the rock face and consequently does not experience the severe wear common to other drilling tools. Therefore, the burner greatly outlasts the drill bit.

b) The increased life of the burner also reduces trip time - the time spent in removing and replacing the drill pipe or coiled tubing - when it is necessary to replace the bit at the bottom of the hole. This time saved can represent on average as much as a full day of rig time for each bit change, when drilling a deep hole with the use of vortex fluid separation.

c) Drill string wear is reduced because the drill string is not rotated, also not required now are expensive drilling tools i.e. Reamers, Hole openers, Burner subs, Drilling jars. under-reamers. Mud motors, etc. When drilling horizontal bores a down hole hydraulic caliper, tractor unit or stabilisers are used to support the burner head to control hole wander.

d) The cutting of slots in the formation by the rotating drill string which is known as key-holing will not be a problem.

e) The diameter of the hole can be varied by merely changing the advance rate of the burner.

f) The uses of multi spallation burners, set vertically and laterally within the drilling head, this allows for maximum steady-state spallation drilling rate, maintaining bore hole gauge, when fractured rock and water inflow momentarily impedes drilling progress and reduces bore hole diameter. The lateral burners remove any ledges formed by water inflow into the borehole by under-reaming. Also an annular nozzle type burner (see Fig. 49) would allow high spalling rates due to improved velocity and with the use of powders like coal dust to increase luminosity and radiant heat transfer rates to the rock.

g) Spallation produces a smoothly finished well bore wall that is ideal for photographic. television equipment or logged with conventional geophysical down hole tools. Spallations' only disadvantage is that it will not allow you to produce a core sample, but it provides a steady stream of rock spalls, of a size that can be used for petrological evaluation.

h) For ultra deep drilling of oil, gas, mineral, geothermal well bores the use of hydro-combustion spallation (high density) compressed air, fuel are injected into the flow of water or drilling mud (fluid) from the rig pumps and transported as bubbles in the water phase. the use of low-density hydrocarbon fuel like kerosene will allow a second stage separation from the water phase after the air. To permit exothermic combustion at depth.

Normal flame jet spallation produces a hole size greater than the expanded flame jet diameter, allowing direct impact of the cuttings against the lower face of the spallation head by the use of water within the fuel, this will stabilise flame reaction to allow spallation drill heads with diameters smaller than flame jet to be used. The jet itself block particle impact and a coating of stellite protects the nozzle ring surface above the sintered nozzle attached to the bottom of the spallation drill head larger holes diameters are possible by spallation reaming. Boreholes with diameters of 48" have been drilled at rates of approximately 12 ft/hr

and holes have been enlarged to 5-1/2 ft in diameter with the same 4" O/D spallation drilling assembly. The technique of sensing the gas products of combustion near the spallations burner head body, any well bore restriction caused by a shoulder forming (ledge) will produce an increase in the gas pressure change is then relayed to the pressure sensors on the water outlet valve control to ease the flow of well bore, this enables effective control of well bore diameter.

With the use of a dual-string system enabling gas lift removal of all the cooled combustion products and rock spalls in a separate annulus or pipe (velocity string) the passage of spalls in the annulus of large deep well bores are impossible without the injection of additional air to provide the necessary lift velocity, large well bores also reduce local gas velocity near the drilling assembly this ultra deep wellbores to be drilled without erosional wear within the wellbore. Low density spallation, a down hole storage system of the fuel phase allows transport of the fuel at very high concentration. True linear drilling results in only pure tension reducing the risk of failure to a very low rate within the drill string.

The Separation of the Multi-Component Flows in Flame Jet Spallation Drilling

Requirements for down hole separation of a slugging multi-component (air/water/kerosine) drilling fluid, as to be used in flame jet spallation drilling as a suitable separation.

Drilling Operations and the Effect on the Supply of Fluids to the Drill Head

In the evaluation of spallation drilling systems so far, fluids have been piped down separately to the drill head and boreholes have been comparatively shallow so the problem of drill string extension with a multi-component pressurised drilling fluid has not been addressed from a practical view point. The crux of this problem is the need to de-pressurise the system whenever a new length of drill pipe is added. This has the effect of cutting off the supply can recommence. Whilst this difficulty was recognised to the extent of having downhole fuel and

air accumulators to sustain the flame, the whole process becomes an increasingly disruptive exercise the deeper the hole gets and so the periodic use of non-return valves in the drill string would seem to be essential. This allows downhole pressures to be sustained and only a limited volume of pipe at the top of the string to be de-pressurised when new pipe is added. Such techniques are already used in air drilling where, typically, a ball, dart or flapper valve is installed every 150m (500') - equivalent to 15 drill pipe lengths or 5 stands of drill pipe.

The use of non-return valves and the length of period over which the supply of drilling fluids is disrupted has important implications downhole. For standard drill pipe, the time taken to attach a new length is around 2 min. The time to re-pressurise the pipe will be dependent on operating pressures/flows, the position of the first check valve and the capacity of the surface compressor but is reported to be in the order of seconds rather than minutes from air drilling experience.

So allowing 1 min for the whole de/re-pressurisation process, the total delay between stopping and starting drilling might be about 3 min. During this interval, fluids within the drill string below the top non-return valve will initially be at least 28 bar (500 psi) above the downhole pressure (representing the flame jet generating over-pressure) so flows of drilling fluids will continue, due to expansion of the gas phase, until pressures within and without the drill head come into equilibrium. This flow will be adequate to sustain a "pilot" flame over the change over period, particularly if the discharges are carefully regulated. However once the main down flow has ceased there will also be a tendency for buoyant separation of the gas and liquid phases to become the dominant process so that ant flow down the drill string would have a relatively high liquid fraction. Gas will collect below the non-return valves and with a potential 60 m of vertical movement for a Taylor (maximum diameter) bubble in a standard 5" drill pipe (0. 102m ID) over 3 min, once the pumping restarts gas bubbles of comparable length could be pushed down to the drill head. It would only take a slight delay in the pipe change over (5 min) for the length of pipe section between non-return valves to segregate, so this condition must be anticipated as well.

Float out will also occur between the kerosine and water components but to a much more limited degree. The non-return valves, however, provide the potential for some re-mixing to take place once the main flow is re-established.

Downhole Separation of Drilling Fluids

The nature of the multi-component flow approaching the drill head can probably best be characterised by its variability. Even under steady state drilling conditions, the volume flow rates of gas and the narrowness of the drill pipe involved dictate a slugging flow regime and with the regular interruptions to the flow when the new pipework is added, increasing dissociation between the phases can be expected. In addition, at the high drilling rates possible for spallation techniques. the time between pipe renewals is soon surpassed by the transit time for drilling fluids between the top and bottom of the hole (may be by depths of only 1000m) after which all fluids reaching the downhole separators will have been through at least one period when the pumps were switched off.

Accordingly, it would seem desirable that the first separator should have a capacity comparable with the pipe volume between non-return valves so that it could function as a slug catcher as well as removing the gas. This would then provide a much more stable flow for the second stage kerosine-water separator which could then be a conventional L/L hydrocyclone.

This concept is illustrated in Fig 50 and 51 and discussed below. Calculations have been based around the operating conditions and pipe/hole dimensions detailed in the Appendix, representing a typical spallation drilling scenario notably a multi-phase flow down the drill pipe comprising 2040sm^3/hr air, 5.5m^3/hr water and 0.15 1m^3/hr kerosine with the return flow external to the pipe.

G/L Separator Design

Volumetrically this is equivalent to that of the drill pipe between non-return valves (150m spacing: - 1.2m^3) with use of a wider bore pipe (6 5/8" (0.127m ID) against 5")

allowing the unit to be shortened to - 105m. On entry the flow is set spinning by a swirl generator, throwing the liquid phase to the wall sufficiently to keep it away from an axial, perforated pipe for gas removal. The swirl also provides a mechanism for bubble separation enhancement. A de-misting mesh adds protection from droplet carryover. Towards the bottom of the separator, when the swirl has decayed, liquid build up will occur and an interface develop. Gravity driven float out of any remaining gas should take place in this region, with the liquid discharged from an annular orifice in the base.

Ideally, the discharged liquid flow should possess a steady concentration and dispersion of oil in water for optimal performance of the following hydrocyclone. Achieving this end is helped by the relatively high downflow velocity of the liquid in the bottom of the 1st stage separator (-0.1 3n1 5) which should carry with it all oil drops below - 2mm for a 300m hole and below - 0.7mm for a 6100m hole. Drops above these sizes would have a higher upward settling velocity. Difficulties in sustaining oil entrainment might be overcome by adding static mixing elements to the lower part of the separator or by using surfactants to increase dispersivity.

The large volume of the G/L separator also provides scope for its use as an air accumulator when drilling is disrupted (see Fig 51).

L/L Separator Design

Principally, the use of a hydrocyclone is anticipated comparable with a G-liner in size and general design, although a high pressure drop version (~ 10 - 15 bar) would favoured so that the effect on throughput of pressure fluctuations, due to slug arrival and more significantly liquid level changes in the G/L separator, is minimised. Operation in concentrator mode, that is with the flow rate for the overflow at a similar of possibly slightly lower level than that of the kerosine in the feed (e.g. a 4% split for a 5% feed oil concentration), provides an oil-rich discharge to a kerosine accumulator which also acts as a secondary gravity separator. Segregation of the water and kerosine components is likely to be

very rapid and a level control device and water drain are required to keep the interface away from the oil take-off. Any air reaching this unit is likely to be due to dissolved gas break out in the hydrocyclone and would get carried through with the kerosine. The amounts of air involved would be small, especially at depth. Presuming operation can proceed as described in Section 4, only a relatively small volume is required for the accumulator (~ 25 litres) making the whole L/L treatment section around 5m in length. Subject to tests. Larger accumulators can be accommodated.

System Control

Would be largely based around pressure sensors and control valves. In particular, compensation for charging liquid heights in the G/L separator (potentially tens of metres) may be requires if the resulting variability of the flow discharging from the hydrocyclone is unacceptable.

Separated Fluid Quality

The suggested system should provide a relatively liquid-free air stream: a kerosine discharge with up to ~ 15% free gas (shallow borehole depths) but < 1% water contamination: and a water stream with perhaps half these gas levels and 1 - 2% kerosine (v/v concentrations at local conditions).

Anticipated Operation of the Fluid Supply System Through the Pipe Extension Process

As outlined when the pumps are switched off to allow the drill pipe to be extended. over-pressurised air is left in the drill string providing a mechanism (in the expansion of the air as the system equilibrates) for sustaining the flow of fluids to the drill head, albeit at a reduced level. As the flow down the drill string is likely to be mostly liquid, because of buoyancy effects, the extent to which the flame can be sustained will depend on the amount of air in the G/L separator. providing there is adequate expansion potential to drive it out.

Residual gas volumes are estimated at 1.0 and 0.75m^3 for 300 and 6100m borehole depths respectively (at local P & T). Taking the 28 bar pressure differential used to power the flame jet under normal drilling conditions as being available for this process (leaving the original hydrocyclone pressure drop to provide the jet energy), expansion volumes would be equal with double these residual amount for the respective 300 and 610Cm depths. If the drill head flow (both air and liquid components) could be controlled to be, say, a tenth that at the drilling condition, this might be sustained for potentially 15 min for the shallow hole and 30 min for the deeper one. This may well be a conservative assessment as it assumes that the back pressure outside the drill head remains constant when, in practice, it will fall to some degree as the substantially reduced flow rate of fluids needs a much lower pressure gradient to get back to the surface.

Once pumping is restarted, the balance of fluids in the G/L separator should return to normal as the gas-rich fluid left in the drill pipe is pushed downhole.

Any downhole multi-component separation system must be able to cope with the consequences of the regular interruption of the supply of fluids during drilling pipe extension, in particular considerable segregation between the gas and liquid phases in the drill pipe.

A separation system is suggested incorporating a high volume G/L separator, which can also function as slug catcher and air accumulator, followed by a L/L hydrocyclone.

Drilling fluid flows and hence, the flame jet could be sustained during pump shut down by the expansion of gas within the drill string, albeit at a reduced level. This would ease the temperature in the well bore and reduce spalling when adding in new stands of drill pipe.

Hardware/Separator Operating Conditions

5" standard drill pipe, ID 0. 102m (4") taking all the drilling fluids (air, water, kerosine - p = 780 kg/m^3 @ NTP); 6 5/8" pipe same size as D/P tool joints for separator/drill head, ID 0.127m (5"): 0.254m (12" to 13") diameter hole taking the return flow and spalls in the annulus outside the drill pipe.

300m (1000') hole

T = 5O°C (geothermal gradient ~ 20°C/ 1000' and supply T = 30°C)

P = 72 barg - 27.6 barg (500 psig) combustion chamber pressure plus 29.4 barg hydrostatic head plus driving pressure for hydrocyclone (say 15 bar).

air = 2040sm^3/hr (1200 scfm) or 30.8m^3/hr at local P & T

water = 4.5 - 5.5m^3/hr (20 - 25 gall (US) /min)

kerosine = 0.151m^3/hr (40 gall (US)/hr)

kerosine-in-water concentration ~3 - 4% (v/v)

liquid-in-gas concentration ~13- 15% (v/v, local P & T)

6100m (20,000') hole

T=450°C

P = 64 barg - 27.6 barg (500 psig) combustion chamber pressure plus 598 barg hydrostatic head plus driving pressure for hydrocyclone (say 15 bar).

air = 2040sm^3/hr (1200 scfm) or 10.2m^3/hr at local P & T water and kerosine flows/concs. as above liquid-in-gas concentration ~ 31 - 35% (v/v, local P & T).

Due to the configuration of the vortex chamber within the centrifuge casing allowing the well bore to be formed by vertical or vertical and lateral spallation jets or either, from the vortex chamber combustion jets, or single jet within the drilling penetrator head, this allows a larger gauge hole to be drilled by the size of the drilling head. Spallation of bore hole rock will be vary fast depending on the bore hole size and formation type and the rate of cooling water from the co-axial nozzle jets.

The down hole motor or turbine as shown in fig 1 produces rapid rotation of the centrifuge or vortex, cyclone chamber when used, fig 7, increase the swirling action of the liquid into a high velocity jet stream, fig 2, so entering the tangential port, fig 8 or 9 item 2,

of the vortex nozzles involute section, to form an ultra high velocity cyclone, fig 8 or 9 item 11, increasing in velocity at each stage of the vortex, the liquid combined with the shape of the vortex chamber, fig 8 or 9, water outlets and de-oiler/air combustion jet tubes, fig 8 or 9 item 13, generates a vortex in the cyclone chamber, the heavy water migrates to the wail of the vortex nozzles as the lighter air or oil separates fig 8 or 9 item 7 to form an ultra-high velocity central core that separates out inside the central tubes fig 8 or 9 item 13. The high velocity water jets also produces pulse jets fig 9 item 8 forces eroding the rock interface simultaneously while acting as a cooling liquid fig 8 or 9 item 10 inside and outside of the centrifuge and vortex jet nozzles and water cooling drilling control by co-axial jet outlets. The tangential velocity profile in the cyclone is shown in fig 12.

A. Central core is forced into the vortex peripheral inlet ducts fig 9 item 3. Inlet orifice fig 8 item 14 in the nozzle jet tube as the air or fuel core is sucked out from the end of the nozzle jet tube for.

B. Water outlets contraction for cooling and fluid cavitation fig 8 or 9 item 10.

C. Outer vortex wall (water) fig 8 or 9 item 4.

The combustion chamber heads can be single or multiple, the nozzle jets can be of various sizes for varying degrees with combustion spallation with the larger sizes within the centre section for maximum spallation/erosion or single all internal areas inside the combustion chambers and pulse jets chambers (if used) are treated by ion implantation or ion diamond like carbon process with ceramic or PDC lined pulse jet chambers if required to minimise splash back erosion of spallation particles exiting the wellbore.

This system of centrifuge/multi vortex penetrator or single fixed head penetrator drilling by combustion jet spallation will drill any diameter of hole at a very fast rate of penetration depending on the size of drilling head used and the amount of vortex chambers jet nozzles used with the centrifuge or vortex, the vortex chambers are designed also to allow for pulsing of the fluid leaving the vortex orifice. Various sizes of vortex chambers and combustion jet chambers can be used for increased velocity through the jet nozzles for high

rates of spallation penetration. Water can also be injected back into the combustion chamber ahead of the fuel and oxidant increasing the kinetic energy.

Compressed air can be injected back into the cooling water ports to the injected combustion chamber water jets, also air injection within the pulse jet nozzle port system, allowing jets of moist air to increase kinetic energy from the thermal spallation jets and pulse jets. The combustion chamber exothermal jet air fuel system can also be positioned back from the water exit orifice to allow for greater combustion jet flame, water impingement increasing kinetic energy down hole separate air or mixture fuel, storage can be placed in any placed in any position within the drill string separation ideally only fuel storage accumulator will need to be used. Heat flux just prior to spallation is the determining factor of the heat transfer which produces an extremely hot dense super critical fluid flowing past the rock surface to be spalled will perform the same as a flame does in jet spallation by combining the two. The storage capacity of the fuel phase allows the transport of fuel in much higher concentrations low density hydrocarbons (kerosine) ideally P4 or P5.

Allowing for good environmental drilling control, all particles, chips and fragments are cleaned by the returning low density steam, and none combustible gases returning the chippings to the surface cleaning and separation system. The system is ideal for onshore and offshore drilling. The most critical problems associated with the mechanical cutting and erosive cutting jet stream, for drilling, boring and the like is stress corrosion or thermal degradation failure of the materials used as the cutting means such material failure limits the ability of the operator to transfer high mechanical energy to mechanical cutters and the erosive problems of splash back by the fluid, water, hammer or cavitation on the fluid as it leaves the jet nozzle on to the rock interface in the well bore the splash back causes a very fast rate of erosion and failure problems and drill string components sticking within the well bore.

The present invention pertains to the high velocity mixed water or drilling fluid, fuel, air, liquid mixture comprising the steps of forming a high velocity, swirling liquid jet by

providing multi-vortex separation chamber (replaceable) fixed units or within a centrifuge casing the tangential ports within the vortex chamber to allow the liquid to swirl. The swirling liquid allows the air and oily stream to separate in stages and enter into the central tangential ports in the central exit orifice tube while the water within the vortex is forced to the outer wall of the chambers for cooling the combustion jet nozzle chamber and by post combustion injection of water allows submerged flame jets cooling water on to the rock side walls, and by cooling the combustion gases to stop spalling by the co-axial water jets to control well bore diameter drilling control by combustion chamber pressure and temperature allowing spallation communication control with the rock interface by combustion jet gases. Means are then provided for injecting high pressure air/fuel/water into the combustion nozzle allowing the fluid into the vortex nozzle chambers for creating a high velocity flow therein. The fuel and water two phase stream is atomised allowing for a better burn within the vortex chamber then discharged through the nozzles with the air into the combustion chamber for exothermic combustion. This allows all types of rocks to be spalled by super critical thermal jet spallation. The swirl in the vortex separation system may by formed by tangential or involuted injection or by a stator configuration which induces the liquid to swirl and by the use of high speed liquid flow introduced tangentially into a swirl generating chamber having a central located flow exit tube of reduced diameter which forms an exiting nozzle from which emerges an air or fuel component ultra high speed spinning vortex jet and the hydrodynamic interaction of the air or fuel component centrifuge vortex flow regimes within the separation system. The placing of a single or the multi jet immediately adjacent to the formation with correct amount of stand off where the thermal combustion jet streams are maximum subsequent to exiting the single or multi-combustion nozzles for maximum spallation on the rock interface and simultaneously cooling penetrator drilling head and combustion jet chamber nozzles or central combustion flame with the high velocity water exiting the nozzle jet orifice axial and co-axial for well bore control.

The use of coiled tubing with one or two internally fitted small diameter flow line to

transport the compressed air and fuel, or either one, if only one tube is used along with abrasives if required allowing either the air or fuel to be mixed with the water for separation within the centrifuge spallation drilling system, a special tubing adapter plate with flow ports to the centrifuge or combustion vortex injectors, to replace flow plate, fig 7 item 6, with bearing and seal assembly, to allow rotation within the spallation drilling head around the stationary tubing adapter plate, or hollow tri-rotor drive shaft, fig 1 item 30, through the spline section and adapter plate with single or double tubing connector unions fitted below pin connector, fig 1 item 21, with flow port for water mixture, for driving the centrifuge motor and cooling allowing high pressures to be used.

Thermal spallation drilling systems use an axially symmetric, downward-facing thermal jet. A different system would result if the same mass flow of high temperature gas super critical water was injected through an annular nozzle whose diameter is approximately the size of the desired hole (see fig. 49).

The exiting supersonic gas would flow inward along the spalling surface until it turns and flows upward into an axially symmetric velocity vent tube. This reversal of the gas direction, along with a radically different location of the high speed gas region will result in a significantly improved spalling action. This will occur in this reversed flow system because the largest quantity of rock must be removed from the outer portion of the spalling surface, precisely where heat transfer rates and gas temperatures are maximised. Removing the cuttings and exhaust gas's, water products through a centrally located coiled tubing or casing this is similar to the method of reverse circulation used in rotary drilling methods. The efficiency of spall removal will improve significantly because of higher gas velocities and the logistics of effluent transfer and solids removal at the surface. The reversed flow process would be applied by enclosing all the utility umbilicals (water, compressed air, fuel and electrical control cable) in the multi coiled tubing {see fig. 44) or by manufacturing the swirl generators hydrocyclone separator system within the annulus of the twin drill pipe as shown in Fig. 49 which is a large diameter dual wall drill pipe. Such a construction would allow the

continuous insertion of each drill pipe stand with storage and vortex separation system. The terminus of the velocity central vent tube would allow separation of the utilities from the waste products, which would exit into a separation system at the surface.

The various portions of the flame jet issuing from the nozzle are supersonic jet velocity of the flame itself "shock diamonds" are characteristics of the situation where unbalanced gas pressures exit. At the exit plane of the combustion jet nozzle the gas pressure (high combustion chamber jet nozzle pressure) is much greater than that of the surrounding atmosphere the jet expands as it passes into the atmosphere, but due to lower sound velocity as compared to jet velocity the jet, combustion pressure and atmospheric pressure do not immediately balance shock patterns result and the jet surface itself alternately expands and contracts the mechanism by which the higher velocity flame jets and two phase water pulse jets if used) are capable of water hammer erosion cooling the heat flux allows faster penetration, drilling faster and producing a smaller diameter controlled bore hole is by increased combustion pressure and chamber pressure and the use of water. The air and fuel liquid mixture separated by the vortex, cyclone or centrifuge invention method, with the circulating water-cooling the combustion chamber jet nozzle that operate red hot to facilitate the intense combustion reactions taking place in the combustion chamber jet nozzle. Using high chamber pressures and two phase water/steam super critical flow this leads to increased drilling speeds with less cross-sectional area, depending on the size of the combustion nozzle chamber. This effect depends in part on the fact that the nitrogen component in air (78% of the mass) contributes markedly by its mechanical effect on the rock or other formation mass, in conjunction with the high velocity of the combustion jet nozzle chamber effluent. Post-combustion injection of water or concentrated fuel/water injection will allow lower temperature flame jets and low temperature mixed upward annulus flow to surface.

Exothermic heat of combustion will produce a mixture of hot super critical steam nitrogen and carbon dioxide for expansion as a subsonic jet. The jet flow at turbulent Reynolds number of three to four million will produce stagnation heat fluxes of 10 to 20

MW/m^2. The returning water flow exiting through the well bore carries enough kinetic energy to overcome any pressure loss and provide sufficient lifting force to return the spalls. Adjustment to hydraulic pressure can be made to intensify any pressure drop across the exit jet nozzles at a level beyond the critical ratio of (2.0) producing a supersonic combustion flame jet. Heat fluxes are very high so post combustion water injection will produce lower flame jet temperatures the swirling jets of various temperatures and velocities as required by surface control, allowing spallation of low brittle and ductile rock with transformation temperatures. The large ratio of water to combustion mixture will allow low temperature increases in the upward well bore flow. Heat transfer co-efficients in submerged combustion flame jets, will provide strong dependence to drilling depth, drilling velocities will reach ultra fast penetration rates, with ease of spallation by increased heat transfer by increased stresses in the well bore from the over burden loading when coiled tubing is used. This would provide only significant limits to the rate of penetration with less handling of drill pipes.

Spallation Combustion Burner Head Fuel-Water-Air Nozzle

The modified nozzle design allows for increased speed of exothermic energy of combustion, by the mixing the kerosine, air and water into a central triple vortex jet, the mixture stream, inside the manifold, the stream under pressure is surround by vortex jets of compressed air of up to 3,000 cfm at 500 psi plus hydrostatic pressure that generating bubble in the mixture flowing through the central vortex nozzle by swirling the liquid mixture at high pressure so that the gas is presented with a greater surface area. The compressed air is fired at high speed into the rotating vortex action kerosine/water mixture the smaller the bubbles the greater the surface area available for absorption. The result produces a plume of atomised droplets, each containing trapped air bubbles, only a small portion of the compressed air feeding into the nozzle, ends up in the centre of the liquid mixture, like small droplets the rest of the compressed air surrounds the plume increasing exothermic energy. Exothermic heat of combustion (ignition) will occur when kerosine to air ratio is in the 5 -

15% range see Fig. 54 also air flowing through the multi radial jets (holes) situated within the second stage vortex swirl chambers at pressures over 200 psig, friction across the jets (holes) will create sufficient heat to cause hot spots which will lead to ignition with the correct kerosine -to air mixture, atomising the water with the kerosine through the second stage vortex nozzle, and valve controls will increase the burn rate of the fuel within the combustion chamber. The shock action prior to discharging the hot super-critical gas products of combustion from the vortex swirl type air discharge chamber, that produces a swirling mechanism prior to the velocity of the hot products of combustions low density that exits the combustion nozzle, the swirling hot products of combustion, impinge on the exit orifice that produces a unbalanced high and low pressure velocity flow, producing a pulsing action within the hot products of combustion. The control of water injected into the fuel flow determines the onset temperature of the hot products of combustion that produces high velocity drilling rates with the use of atomising the water in with the kerosine fuel that produces a super-critical jet flow. The full amount of water to cool the well bore may not be required on the more ductile rocks. The water used to cool the well bore will controlled with a valve, in the injection manifold.

Abrasive particles may be added to the liquid mixture to aid the abrasive (erosion) cutting, where required to be separated out by the vortex, cyclone or centrifuge method within the invention, for erosion, cutting, spailing of the soils, sedimentary, igneous or metamorphic formations. The invention also uses the cooling water to control the bore hole size, as shown in fig, 45, item 3. The size of the bore hole is not achieved until the combustion spallation head has progressed well down the bore hole, when spailing rock formations the bore hole widens upwards from the bottom, reaching maximum size, size is controlled by the water injection which will cause its impingement against the bore hole wall rock surface terminating further erosion, cutting spalling action of the hot flame gases. Different size penetrator drilling heads and angle of nozzles result in the water striking the hole at different distances above the bottom of the well bore. Abrasive particles passing

through the combustion chamber head exits at over 1,000 it/sec through one or more tungsten carbide or stellite nozzles particle velocity is approximately four time that of cold compressed sandblasting with a sixteen fold greater energy release in impact.

The water quench outlets fig. 45 item 3 can be set at any angle so terminating erosion, cutting and spailing action, allowing the bore hole size to be only slightly larger that the penetrator drilling head, the controlled use of water within the combustion jet nozzles allow for decreased nozzle sizes to be used with smaller combustion jets, allowing for favourable results using much higher chamber pressures. For the combustion jet chamber allowing the use of higher air pressures up to, 3.000 s.c.f.m. at 500 p.s.i.g. plus hydrostatic pressure or more, with higher combustion jet velocity. The tangential velocity increase radially outward from stagnation point is immediately very high leading to an actual erosion, cutting, spailing rate which is at the bore hole the speed of bore hole advance is greater, hole diameter is held to a dimension only slightly larger than the penetrator head, thus increasing the vortex chamber pressure significantly. Greatly increases the drilling penetration rates, where air provides the necessary oxidant and the inert component of air contributes to the mass flow at high temperatures and velocities. Nozzles with co-axial water outlets can be placed in the outer penetrator drilling head ports to control bore hole size and axial water pulse/jets outlet nozzle jets for maximum erosive action. Abrasive drilling can be used either alone or in conjunction with combustion jet spallation to add significantly to erosion action of the particles with increased kinetic energy and well bore control. Increasing linear drilling speed. Allowing more effective penetration rates to be maintained in deep sedimentary and igneous, metamorphic formations in the range of hundreds of metres per hour from the largest RD down to 4½" RD well bore size. It is notable that while the volume of material removed in the latter cases is actually less the action is far more effective in terms if linear drilling speed.

With Worldrill's unique and novel gas liquid vortex generator hydrocyclone method separates air/fuel (kerosine) from the water by the effect of vortex separation, for air, fuel

from the abrasives and water with complete absence of turbulence by the swirl generator and atomising of the fuel/water producing a super-critical thermal jet with high velocity flow allowing rocks with low brittle to ductile transformation temperatures like limestone, basalt, phyllites etc. to be spalled including permafrost and heat flux control. Abrasive particles will not cause abrasion, as the abrasive peripheral grit will not move outward to the chamber walls, the finest oil droplets together with the air and water and or abrasive particles are pressurised in to the combustion chamber jet nozzle creating a subsonic to supersonic flame jet for spallation. This spallation drilling system is ideal for any drilling angle, horizontal, "S" or "J" type drilling, additionally stellite tungsten carbide or PDC inserts can be used for abrasive and high temperatures nozzle applications within the combustion chamber. The vortex nozzles at the end of the water cooling systems jet nozzle head, surrounding the central spallation jet this quench method could stop the use of co-axial water for controlling well bore size.

The novel method of well bore diameter drilling control is with the use of a circular water housing, as shown in fig. 28, item 20, provided with a ring of water jets fig. 28, item 22 with feed from the bottom vortex swirl outlet downwards, to impinge the jets of water against the rock face terminating further erosion/spalling of the hot flame gases to gauge the well bore.

The unique and novel method in fig. 27 and 28 shows the combuster chamber nozzle fig. 27 and 28. item 6 combusts fuel and an oxidiser in an enclosed chamber fig. 27 and 28 item 2 and 3, to produce an intensified supersonic flame jet fig. 27 and 28 item 4 through nozzle orifice fig. 27 and 28, item 5 the flame spalls the rock to form the bore hole. The flame jets or jet impinges against the bottom of the bore hole, penetrating, erosion, spalling is very fast as additional heat is added by the hot gases passing upwards through the well bore. The spalling of the well bore is controlled by the high velocity cooling water fig. 18 and 28, item 22 exiting the co-axial outlet ports in the vortex nozzle body, a further technique for producing, controlled bore hole diameter is the use of adding solid particles to the flame jet,

by the surface injection of abrasive particles such as hard sand to provide a novel and rapid cutting action through vortex separation flame jet produce a controlled well bore diameter with increased rates of penetration due to the control of the gases spalling/eroding the hole faster. The use of water and abrasives together with intensified jet velocity of over 6,000 ft/sec., and above. For air fuel mixture allowing for a much higher combustion chamber jet nozzle intensified chamber pressure about 500 p.s.i.g plus hydrostatic pressure allowing for tangential velocity increases, radially outwards from the centre of the well bore, with air supply of up to 3,000 s.c.f.m. allowing ultra fast drilling speeds.

In the spallation process, the spalls can be blown from holes as large as 2½ inches in diameter, and holes can be formed up to 5½ ft in diameter with a 6 inch diameter burner and combustion air flows of above than 1,000 scfm. This is because the cavity formation by spallation should be equal to the drilling programme for deep, small diameter holes. Cavity formation as shown in Fig. 48 with the seals around the drill pipe and the exhaust pipe. The disposal of waste is an increasingly important problem world wide. Deep storage velocity gasses in the exhaust pipe were removed at a faster rate. The size of the particles that are formed by spallation is a function of the rate at which heat is transferred to the rock surface. The higher the heat transfer rate, the smaller the spalls that are produced. As the cavity increases in size, the gases cool before they reach the cavity walls and also the thermal flux due to radiative transport from the gases to the cavity walls decreases. These two factors reduce the rate of heat transfer to the rock and cause the formation of latter spalls. Also when the spalled hole is used as the exhaust duct, the exit velocity of the exhaust gases decreases as the hole diameter increases, thus reducing the ability of the gases to lift the spalls from the hole. Thus in larger holes the larger spalls and the lower gas velocities contribute to make the removal of the spalls more difficult.

To produce cavities of larger diameter, two changes can be made to the system. They are:

(A) increase the burner size or multi burners and the fuel and air supply to this larger

burner. (This will not only provide the additional heat required for spallation at a greater radial distance from the burner but also will increase the amount of exhaust gases available to carry the spalls from the cavity):

(B) emplace an exhaust pipe from the surface to the bottom of the hole and force the gases to exit the hole through this pipe by sealing all other exits at the surface. Thus the exhaust gases will have a much higher velocity and will be capable of lifting larger spalls to the surface.

Uses for Underground Cavities in Hard Rock

There are many uses for underground storage cavities. Some of them demand immediate attention. Development of the spallation process will make these caverns, cavities and shafts in hard rock ideal for, petroleum and natural gas storage at present they are largely stored in metal tanks on the surface where they are very vulnerable. Some work has been done toward storing these valuable commodities underground but still the large portion of the served reserves are still above ground in metal tanks. Spallation could create inexpensive cavities for storage of these products in areas where proper rocks are available. In Sweden, storage basins for solar-heated hot water are mined in granite rock by conventional methods. This water is heated during the many hours of daylight of their long summer days, and then the heat is used for space heating during the dark cold months of winter. The application of spallation chambering for the production of these basins should make this system more economical.

Storage of these wastes for disposal, like nuclear waste spallation excavation would be most valuable. Chemical waste can be often be decomposed by high pressure and high temperature reactions.

Providing the retorts to meet these requirements above ground is very expensive. Such retorts can be mined by spallation methods in granitic rock or kerogen rock where the overburden pressure and therefore the containment pressure increases by over a pound per

square inch for each foot of depth and where the rock would not be affected by any reasonable temperature requirement. Here production of cavities by spallation may provide a unique solution to a difficult problem.

Two or more small caverns at medium depth in granite (crystalline rock) to store gas or liquid's connected inside by micro tunnels see Fig. 53 and will operate at higher pressures than conventional large low pressure salt dome caverns the other advantage with crystalline rock caverns, it will not close up over time with salt creep and can store the same amount of working gas as a much larger, shallower cavern operating a lower pressures. The time to construct smaller cavern in granite will be extremely fast in comparison to salt domes, and would have significant cost savings over leaching out a salt dome cavern. The two or more granite caverns could hold 6 billion scf of working gas this would take less than one year to construct in comparison to salt domes, to engineer, procedure the required equipment, and construct and de-water after leaching 7.0 million BBL. salt cavern to store 6 billion scf of working gas, would take 3½ years, most salt dome's are 200ft in diameter and 80ft deep. To construct a cavern of this size, the logistics to supply and inject 1.3 billion gallons of water and disposing of same amount of brine must be made, a major problem. One advantage for deep or shallow caverns is the amount of adequate roof thickness for stability and integrity when under gas or fluid pressure.

Tunnelling

Spallation can provide a system that can improve advance rates and reduce costs of tunnelling in hard rock. The conceptual system shown in Fig. 46 describes a method which could be developed to provide rapid mining of tunnels. By a horizontal coiled tubing injector head. There would be work required in developing and testing such a system, but because of the present high costs of tunnelling the feasibility of a spallation tunnelling is very economic and fast.

Re-Entry Drilling Applications

1. Short, medium and long radius drilling.
2. Debris removal from well bore, full gauge cleaning.
3. Tubing cutting.
4. No setting of whip stocks or milling side track.
5. All re-entry work completed with spallation drilling trajectory assembly.

The use of a storage system or accumulator as described in the trajectory control unit, can also be used as a drilling back up system for pressure storage of fuel (kerosine) for continuous drilling when adding new stands of drill pipe to the drill string, the accumulator is provided with a non-return valves fitted within the central tube, or drill pipes or through the accumulator. The accumulator is fitted with a constant rate spring loaded piston or pressurised air piston controlled be electrical valves from the surface, or alternative weight set (over pull) piston with a central tube piston rod. The accumulator comprises a piston under pressure within the cylinder, the mixture charges the accumulator piston by the two way servo electrical control valve fitted into the body of the accumulator, by over pressure from the surface rig pumps. This pressure back up drilling system is for continuous water, air, fuel mixture pressure to or from the vortex, cyclone centrifuge and/or motor controlled by the two way control valve, allowing the accumulator back up system to maintain line pressure every time the pumps are stopped. To add drill pipe stands or coiled tubing to the drill string, the accumulator storage would be sufficient to provide a back up pressure system when drilling, by the use of surface and down hole sensor controls. Within the scope of the invention it is also possible to use an electromagnetic motor or electrical motor and with appropriate modifications and seals the use of centrifugal or vane type motor for temperatures up to 550°C. A gas or bladder type accumulator can be used. Electrical servo control units can also be used to control the trajectory and orientation control units in place of pressure controls. These are also included within the invention.

Trajectory Control Spallation Drilling Unit

Summary of the Second Aspect of the invention

The epitrochoid tri-rotor motor is classed as a rotary motor of positive displacement. Its action is one of rotation not reciprocation. The motor is made up of a motor housing with its inside machined out to an epitrochoid shaped working chamber with a periphery inlet and outlet port on either side of the two lobed epitrochoid volume chamber. The volume can be altered by movement of the tri-rotor in a continuous, circular, movement with the continuous rotation together with eccentric bottom crank guide giving the motor perfect balance and a smooth operation, with twin motors, the motor is driven by the drilling fluid mixture of water, oil and compressed air. The tri-rotor is shaped lake a slightly round sided equilateral triangle which has an orbital rotation inside the chamber. The geometric shapes of the rotor and housing are derived from a group of curves generically called trochoids which are found by revolving one circle around another, and plotting the path of a point either on the circumference, or an extension of the radius of the revolving circle. The housing of the pump is shaped like a two lobed epitrochoid. The rotor has two concentric chambers either side and fitted to the bottom of the top chamber is a shaft with outer facing gear teeth fixed to the centre of the chamber, it is rotated by larger female drive head with inward facing gear teeth and fitted centrally to the pump epitrochoid chamber but concentric to the tri-rotor centre chamber, as the drive head turns concentric to the orbital, eccentric, rotation of the tri-rotor. The size of the drive head with female gear teeth that drives the fixed male gear teeth shaft in the top of the tri-rotor chamber determines the basic geometry of the motor. When this ratio is large, the sweep volume in the chambers is comparatively small and the drive head, female gear, must be small. This limits the size of the fixed male gear shaft in the top tri-rotor chamber. As the tri-rotor rotates in an orbital path, fluid is forced in through the two inlet motor ports with a large sweep volume it generates a high discharge pressure out through the pump outlet ports that diffuses the liquid providing a more controlled flow and a more

efficient conversion of velocity head into pressure head. The head is generated by the lifting action of the tri-rotor and the inner chambers into the centrifuge for separation of the oil and compressed air from the water. Speeds over 300 rpm will cause centrifuging, depending on the surface pump injection pressures to drive the down hole motor in the centrifuge.

The unit has four main parts: from left to right of the full assembly drawing these are the metering valve and its housing; the rotary actuator, the motor, the swivel sub assembly and the spallation centrifuge vortex jet drilling head.

The metering valve is controlled by pressure pulses from the surface. It is shown in the "pulsed" position. Clean water, oil and air from the rig pumps is passing along the central bore pipe and into the metering chamber (the larger of the two). When the chamber is fall, as shown, the motor will have through a defined angle.

When the pressure pulse dies away, the spool in the smaller (right hand) cylinder moves to the tight and vents the metering chamber to the drilling annulus. The left hand spool returns to its rightwards limit under the action of its spring. The rotary actuator is now hydraulically locked from rotation.

When the next pulse comes the pressure from the drilling fluid surrounding and flowing past the valve initially acts on the small seat area shown. When the pulse pressure overcomes the spring, the full spool area is under pressure and the valve immediately opens again to the position shown.

The rotary actuator comprises a large area piston under drilling fluid pressure and a rotary shaft controlling the swivel sub assembly pressure, clean water and air to the rotary actuator. The stroke is sufficient to provide 24 metering pulses. The drilling fluid flow is down a central tube through the piston.

The motor shown is an epitrochoidal type and two inlet (entry) ports end is directly fed from the swivel sub assembly drilling fluid flow through the motor tri-rotor which moves eccentrically.

The driveshaft end of the motor is connected to the spallation drilling head to the swivel

sub. A disc shown at "D" is solidly connected to the rotor and seals the rotary actuator end. It has a key shown in the (vertical position) connecting to a central floating disc. This has a vertical key way on its left side and a horizontal one on the right side. This latter is engaged by a key on the disc shown at "E" winch also carries the bearings. This disc rotates on centre connected to a specifically shaped eccentric cam.

This cam, shown at "F" engages two forks on the swivel sub, which can pivot through a small angle in a ball joint assembly. The drilling fluid passes through the assembly as shown, all in the cross anti-rotation plate fitted through the forks on the swivel sub stops any rotational movement, fig 37.

The purpose of the trajectory control unit, briefly stated is to control the direction of drilling from the surface. The design proposes to achieve this by three main elements: a swivel sub joint with zero to 3° directional movement, an actuator to produce that movement, and a valve to control the actuator by pressure pulses injected into the drilling fluid line at the surface. It is important subsidiary aspect of the design that a through bore or flow ports be incorporated for the drilling fluid, to the spallation drilling head, electrical control of the hydraulic actuator by valves in a closed hydraulic sealed system can be used.

The means of applying pressure to power the actuator may either direct drilling fluid pressure, or some form of accumulator, because the actuator working pressure can be chosen instead of using whatever drilling fluid pressure is available because the actuator pressure is then a constant proportion of drilling fluid pressure. Obviously in either case the number of actuations possible before tripping to recharge the accumulator must be acceptable. This valve is actuated by a pressure pulse in the drilling fluid line, and on actuation meters a defined volume of fluid through the motor. The required surface control feature thus results from correct sizing of the various elements to achieve for example 1 pulse = 0.25° of trajectory change.

The valve meters the flow out of the motor, but it can conveniently be positioned at the upstream end of the assembly, it is designed to actuate within a "window" of drilling fluid

pressure. For instance, it normal pressure was 1,000 psi, the valve could be arranged to actuate, once the pressure reached 1.200 psi. After actuation, the pressure would have to fall back to below say 1,100 psi before another actuation was possible. The same pressure telemetry control valve can also be used to control, fuel water mixture for controlling the heat flux from 500°C to 1,800°C within the spallation head, without the use of outside electrical armoured cable.

The alternative method is to place the two stage vortex separation units, along with the storage and/or accumulator units, above the trajectory control unit and provide flow tubes from the vortex separation units for the fuel and air through the trajectory control unit's bore, allowing a single re-injection combustion spallation head to be fitted to the trajectory control unit for short, medium and long radius drilling control, as shown in fig. 38 for coiled tubing use, or any other combination within the drill string or type of connection.

Spalling and Erosive Intensity

The erosive intensity of the high velocity liquid water pulse jet combined with the supersonic spalling action of the combustion flame jet enhances the erosive, spalling intensity, oscillating the velocity of the jet at a preferred strouhal number and impinging the pulsed jet against a solid surface to be eroded and spalled exiting the liquid so as to structure itself into discrete vortex rings, normal to the axial direction of the jet stream, such a liquid jet will pulse more violently due to the central supersonic flame jet increasing erosion harnessing the pressure differentials over radially spreading vortex as it impinged and passes over the formation boundary provides both axial and rotational forces acting to induce directional factors to improve erosive/spalling results. Thermal hydraulic behaviour in spallation drilling, erosion, water hammer or fluid transients can occur, causing severe damage, the primary cause is the occurrence of a two phase from single phase in the hot water or steam exiting the outer orifice around the combustion chamber.

The multi stacked vortex/cyclone system is ideal for coping with air, fuel, water and/or

abrasive particle mixtures, because the lighter of the mixture's make up gathers at the centre of the cyclone creating the pressure where it is cushioned by surrounding remaining fluid.

Multi stacked vortex/cyclones swirl generators/hydrocyclone as described in the first aspect of the invention, allows for air, fuel, water and/or abrasives to be separated by enhanced centripetal forces either by velocity flow or mechanically induced flow in stages, forces exceeding 1000g inside hydrocyclones provide virtual instantaneous separation in seconds, the lighter of the mixture migrates to the low pressure core inside the separator tube, moving in the opposite direction from the main flow of clean water when multi stacking vortex/cyclones individual separation stages. The invention allows for four methods of controlling well bore diameter through the use of vortex/cyclone and/or centrifuge.

1. Combustion chamber pressure.
2. Control of combustion gas pressure/heat flux/ super-critical water.
3. Water cooling (spall) gases.
4. Abrasive particles within mixture

This method is used to control well bore diameter by continual under reaming, to a size beyond the outside diameter of the spallation penetrator head either fixed or rotary. Allowing for true linear (vertically held) drilling, eliminating drag and friction forces on the drill string or coiled tubing (umbilical) allowing for larger well bores with a wide range of applications within the drilling industries, that are not possible with conventional rotary drilling, methods. One major advantage of coiled tubing drilling with spallation drilling heads is its ability to drill under pressure/under balanced.

The invention allows for two phase injection and centrifugal, vortex/swirl generator, hydrocyclone and/or centrifuge separation to separate air from fuel and water, and the fuel from water, and or abrasive particles from water, by this method separate each of the constituents from the liquid to accommodate periodic injection of air or fuel to the combustion chamber control and air flow into the vortexing water swirl as shown in fig. 30,

31, 32, 33, 35 and 38.

The method further uses a down hole metallic flexible armoured cable attached to the drill string by various means to allow for instrumentation and diagnostic control of air/fuel injection rates, spall lifting capacity by air/water injection, penetrator stand-off clearance, allowing fast penetration rates. The diagnostic measurements allows for flame temperature, combustion chamber pressure, well bore spallation area pressure and gas cooling temperature, velocity to control well bore diameter and trajectory, orientation control. Development of sensors for the smart drilling system to control drilling system to control drilling perimeters for detecting and measuring will be manufactured and used by those skilled in the art of diagnostic and control of down hole functions and measurements. This system allows for continual use of coiled tubing (titanium coiled tubing) will allow the drilling depths of about 50,000 feet at penetration rates of hundreds of metres per hour through the use of umbilical coiled tubing or drill pipe as shown in fig. 29 consisting of outer coiled tubing to transport water, or can be used as spall return line in a dual string low-density combustion flame jet spallation system, with two internally fitted small diameter coiled tubings and an electrical conductor line for instrumentation and diagnostic control of super critical/supersonic and subsonic combustion thermal jet spallation and by the alternative use if water and/or with the small or internal lines. Sections of coiled tubing can be joined by umbilical connectors. As described in our co-pending patent 9305449.2 or other jointing methods. This would allow coiled tubing to be subject only to tension, reducing the risk of down hole failure. The coiled tubing spallation drilling head design would be similar to that as shown in fig. 38.

The use of subsonic (low density) jets, from small co-axial exhaust (bleed) ports in the chamber wail of the epitrochoidal cylinders will also provide ideal mixing and high velocity flow through each of the four trochoidal cylinders, this allows velocity head to be converted to pressure head for continual vortexing and combustion down hole, with the use of a non-return valve fitted to the drilling flow line. To provide a storage accumulator or down hole pressure storage of air and/or fuel will allow for continuous drilling when adding each new

stand of drill pipe, allowing for continual velocity of the drilling fluid and fluid/combustion gas returns, exiting gas/water stream lifting capabilities must always exceed quantities of formation water or pore fluids within the well bore. Drilling to deep depths will require high density liquid water, as the heat flux determines the rate of penetration and temperature of spallation. Heat flux into the rock surface just prior to the spallation is the determining factor in this process of penetration rates and onset temperature of spallation, the heat transfer process. The very hot dense super critical fluid then flowing past the rock surface to be spalled will perform additional spallation in conjunction with the supersonic thermal jet spalling action. This thermal supercritical spalling action allows full rig floor control over the threshold temperature when the rock heats up, below this temperature the rock gets ductile and stops.

The use of abrasive particles or drilling muds can be used with the flame jet or water jet, the use of cooling water exiting the axial outer nozzle orifice, will produce high velocity liquid water erosion in conjunction with the exiting supersonic or subsonic combustion thermal jet whereby the erosive/spalling action of the hot super critical water vortex rings are super imposed onto the heat flux induced spallation action of the same jet the advantage of inducing acoustic coupling to transfer energy to the rock interface in an oscillatory mode, that will further enhance rock failure by increased spallation drilling rates. By this drilling system, spalling and eroding the well bore interface by the super critical thermal jet impinging on the rock surface ahead of the drilling penetrator head with little or no mechanical contact. This eliminates wear, under reams the well bore making this the ideal drilling tool for vertical and trajectory orientation control with this guidance system, that will not deviate from the pre-set trajectory, set from the surface.

The effect of stand off distance of the spallation had to well bore interface will maximum rock spallation removal, heat flux of jet impingement on the concave cavity formed by the advancing spallation drilling head action is very important, between 2½" and 9" providing ultra fast (penetration) drilling rates. By control of the weight of drill string on

the weight indicator on the drill floor.

Continuous drilling is allowed by the use of the vortex cyclone separation system and pressure storage cylinders or accumulator can be assembled inside a tubular drilling assembly along with electronic instrumentation, sensors and control valves controlled by the use of an electrical conduit cable. The tubular drilling assembly will be provided with two box connections in the sub-assembly and the bottom sub-assembly will house the thermal jet nozzle assembly pack. Velocity head can be converted to pressure head also by a down hole pump or motor, allowing continuous drilling.

Summary of the Third Aspect of the Invention

Separation of Multi Component Flow in Thermal Jet Spallation Drilling

Hydrodynamic forces power fluidics are based on the physics of centrifugal and free vortex action in an enclosed space for fluid separation. The vortex cyclone internal chamber is rotated by the velocity of the fuel-air water mixture, that is rotated by the centrifuge motor, allowing the mixture to enter through the co-axial inlet port in the vortex cyclone chamber top body by rotating the axially oriented impeller integral with the bottom axial peripheral ducts and central flow cone, all integral with the inner cyclone chamber. The inner cyclone chamber is supported by bearings and seals, top and bottom, within the fixed outer casing. When the cyclone chamber system is used singular without the use of the centrifuge the top impeller, peripheral ducts and central flow cone will be rotated by the epitrochoidal motor's bearing shaft assembly, with the flow into the inlet being axial. To prevent droplets breaking up by the non-rotation of the drill pipe or coiled tubing and motor design, stops any vortexing, swirling of the liquid prior to entering the fixed axial inlet ports above the centrifuge. The larger droplets in the liquid mixture which is rotated initially by the top impeller that separates out and gradually coalesce in axial ducts before moving along the central flow cone towards the axis of the cyclone rotation by the centrifuge causes the liquid mixture combined with the shape of the de-oiled water outlet to generate a vortex in the

cyclone chamber, the tangential velocity profile in the cyclone. the centrifugal acceleration forces in the vortex are so high that even the finest droplets are forced in to combustion tube core of air/oil in the centre the core is sucked out from the end of the cyclone either axial or co-axially.

Supersonic Spallation Noise For Seismic Signals

A variable supersonic pure tone sound is produced at the spallation drilling head within the interface of the well bore. Seismic sensors are placed outwardly of the well head and detect the reflected seismic signals, generate by the down-ward travelling tone. A pure vibration tone with a frequency that is directly related to flow conditions. The frequency of the vibrational tone is approximately equal to the angular velocity of the flow as it nears the exit of the sound produced will vary directly with fluctuations in flow this can be used seismic measurement while drilling and electrical logging data generation in select cutting and spalling applications utilising the present invention.

The production of a supersonic tone noise with a range of frequencies occurring in the sounds emitted from the spallation drilling head allows the tone to varied through the flow of the fluid high pressure (super critical steam) and combustion gases flowing through the spallation drilling head and the well bore, for enhancing the detection of seismic signals by noise protection and converting the noise into data. Thermal jet spallation acoustic sounds are ideal for telemetry control acoustic can transmit data hundreds of times greater than mud-pulse methods and can be transmitted well over 30,000' for advanced drilling systems. Wave propagation and directional control of acoustic waves within the well bore of formation. Directional drilling systems used in oil and gas wells are primitive tele-operational systems. Directional sensors and formation evaluation tools operate autonomously just behind the drill bit, but all steering decisions and operations are remotely controlled from the drill rig. Telemetry of the data to the surface occurs via encoded pressure pulses superposed upon the mud flow. The data rate of mud-pulse telemetry is very low, allowing transmission of only

simple navigational parameters. Technology development in the measurements while drilling service industry has stagnated because of this data rate limitation. The drilling industry has looked for alternatives to mud- pulse telemetry. Acoustic telemetry can transmit data more than 10,000' at data rates about 100 times greater than mud-pulse methods. Using a single repeater, data can be transmitted over 30,000'. Acoustic telemetry appears to be the key technology for meeting the telemetry needs of advanced drilling systems.

Vortex, Cyclone, Centrifuge Spallation Methods for Air, Fuel and Water

Fig 25 shows an arrangement whereby the hot water phase supercritical outlets, item 1, can be to the outside and the air, fuel mixture will be to the centre, item 2,jet. With this type of centrifuge of vortex cyclone arrangement it is intended that all types of engineering designs are included with the patent for velocity on mechanical induced flow vortexing, cyclone and centrifuge use including coiled tubing usage within the patent. Gearing can also be used to drive more than one jet nozzle, vortex cyclone as shown in fig 18.

Alternating Swirl Type Generator For Compressed Air, Liquid Mixture Separation

The use of a alternating flow blades swirl type generator with left and right hand curved stationary blades set between 45° to 90° angles (can replace the screw type swirl action as shown in Fig. 51). The entering high pressure (water, fuel, air) fluid mixture stream if forced to swirl in a more controlled centrifugal pattern throwing the water and fuel to the outer wall to drain down to the bottom, vortex baffle containment disc, that isolates, separates the liquid from the vortex swirl at the bottom of the unit directing the water / fuel mixture to the drain passage, preventing them from being re-entrained, all the compressed air is sucked to the central inlet filter tube, through the stationary alternating flow blades of the swirl generator see Fig. 54 this allows a smaller diameter integral drill pipe with a swirl generator separator inside, with internal tube centralisers, allowing joints to be made up more easily.

Detailed Description of the Preferred Embodiment

The embodiment of the invention will now be described by way of example only, and with reference to the accompanying drawings in which fig 1 shows a radial cross-section of a combustion jet spallation trajectory drilling system. Showing:-

ITEM 1	Shows	Box thread in drilling tool body
ITEM 2	Shows	Volume Adjustment Metering Valve Setting
ITEM 3	Shows	Trajectory Volume Control Piston
ITEM 4	Shows	Trajectory Volume Control Inlet
ITEM 5	Shows	Trajectory Volume Control Outlet
ITEM 6	Shows	Pressure Pulse Inlet Valve Spool Port
ITEM 7	Shows	Pressure Pulse Valve Spool
ITEM 8	Shows	Pressure Pulse Inlet to Valve Spool
ITEM 9	Shows	Drilling Fluid Inlet Port
ITEM 10	Shows	Bearing Rotary Cam Shaft
ITEM 11	Shows	Connection Pin and Box Valve Body to Actuator Body
ITEM 12	Shows	Actuator Piston Seals
ITEM 13	Shows	Helical Type Bearing Journals
ITEM 14	Shows	Actuator Piston
ITEM 15	Shows	Bali Bearings
ITEM 16	Shows	Actuator Cam Shaft
ITEM 17	Shows	Actuator Base Body for
ITEM 18	Shows	Swivel Sub
ITEM 19	Shows	Connection Pin and Box Actuator Body to Swivel Sub Body
ITEM 20	Shows	Ball Joint of Swivel Sub
ITEM 21	Shows	Pin Connection Swivel Sub to Twin Epitrochoidal Motor Body
ITEM 22	Shows	Tri-rotor Piston
ITEM 23	Shows	Epitrochoid Cylinder

ITEM 24	Shows	Pin and Box connection to Rotary Thrust Sub to Centrifuge Penetrator Drilling Unit Head
ITEM 25	Shows	Bearings (Thrust)
ITEM 26	Shows	Seals
ITEM 27	Shows	Penetrator Drilling Unit Head Body
ITEM 28	Shows	Pin and Box Connection for Retaining Vortex Nozzles and Flow Plate
ITEM 29	Shows	Vortex Combustion Jet Nozzles
ITEM 30	Shows	Centrifuge Drive Shaft
ITEM 31	Shows	Shaft Retaining Bearing Ring
ITEM 32	Shows	Splines in Tri-rotor Gearing
ITEM 33	Shows	Seal Cup Bottom on Actuator Cam Shaft
ITEM 34	Shows	Metering Valve
ITEM 35	Shows	Splines on Drive Thrust
ITEM 36	Shows	Cam on Actuator Shaft
ITEM 37	Shows	Anti-Rotation Plate
ITEM 38	Shows	Forks in Swivel Sub
ITEM 39	Shows	Outlet Port From Bottom Actuator Pressure Cylinder
ITEM 40	Shows	Flow Tube and Anti-Rotation Tube Through Piston for Trajectory Control to Spool Outlet Valve
ITEM 41	Shows	Rotary Actuator Body
ITEM 42	Shows	Seals in Actuator Piston
ITEM 43	Shows	Swivel Sub End Casing
ITEM 44	Shows	Valve Body Section Casing
ITEM 45	Shows	Spallation Drilling Head Wear Guide Pads
ITEM 46	Shows	Inlet Ports to Epitrochoid Motor
ITEM 47	Shows	Bore Through Rotary Actuator
ITEM 48	Shows	Flow Ports (Drilling Fluid)

ITEM 49 Shows Epitrochoid/Tri-rotor Motor Body

ITEM 50 Shows Tri-rotor Seal in Epitrochoid Cylinder

ITEM 51 Shows Outlet Ports from Epitrochoid Motor

ITEM 52 Shows Drive Shaft Crank Tri-rotor

ITEM 53 Shows 0 to 3 Deg Inclination in ½ Deg Increments through Telemetry Pressure Pulse Control in the Trajectory Control Unit

ITEM 54 Shows Recharging Valve

ITEM 55 Shows Retaining Ring

ITEM 56 Shows Seal for Anti-Rotation and flow Tube

FIG 2 Shows Axial Cross Section of Epitrochoid/Tri-rotor Hydraulic Motor Pressure Section (D) First Motor (E) Second Motor

FIG 3 Shows Axial Cross Section of Section (A)

FIG 4 Shows Axial Cross Section (B)

FIG 5 Shows Axial Cross Section (F)

FIG 6 Shows Axial Cross Section (G)

FIG 7 Shows Radial Cross Section of a Penetrator Head Showing the Vortex Chamber Nozzles and Jet Burners in the Centrifuge Chamber Casing Showing:

ITEM 1 Shows Centrifuge Casing Top

ITEM 2 Shows Spallation Drilling Head Wear Guide Pads

ITEM 3 Shows Centrifuge Casing Sub Lower

ITEM 4 Shows Inlet to Centrifuge

ITEM 5 Shows Pin and Box Connections

ITEM 6 Shows Vortex Nozzles Retaining Place

ITEM 7 Shows Centrifuge Lower Chamber

ITEM 8 Shows Vortex Jet Nozzle Burners

ITEM 9	Shows	Nozzle Tangential Inlets
ITEM 10	Shows	Upper Centrifuge Chamber
ITEM 11	Shows	Flow Ports

FIG 16	Shows	A Diagrammatic Drawing of a Combustion Centrifuge Vortex-Jet Spallation Drilling System Showing:
ITEM 1	Shows	Drill String or Coiled Tubing
ITEM 2	Shows	Orientation Unit
ITEM 3	Shows	Stabiliser Unit
ITEM 4	Shows	Dump Valve
ITEM 5	Shows	Trajectory Control Unit
ITEM 6	Shows	Swivel Sub Assembly
ITEM 7	Shows	Epitrochoid/Tri-rotor Hydraulic Motor and Bearing Assembly Drive Head
ITEM 8	Shows	Spallation Drilling Unit

FIG 14	Shows	A Radial Cross Section of an Orientation Drilling Unit as shown in Patent PCT/GB 94/00515 & Others
FIG 15	Shows	A Radial Cross Section of a Dump Sub as Shown in Patent above
FIG 13	Shows	A Radial Cross Section of a Telemetry Control Valve as shown in Patent above
FIG 8	Shows	A Radial Cross Section of a Vortex chamber with Co-axially Removed Water Outlet Chamber Showing:
ITEM 1	Shows	Outer Wall for Water
ITEM 2	Shows	Tangential Inlet Port
ITEM 3	Shows	Water Outlet co-axial (or) axial
ITEM 4	Shows	Reducing Section

ITEM 5	Shows	Taper Section
ITEM 6	Shows	Parallel Section
ITEM 7	Shows	Central Core Oil Tube
ITEM 8	Shows	Cup Section
ITEM 9	Shows	Tube Orifice Outlet
ITEM 10	Shows	Outer Wall for Water Cooling
ITEM 11	Shows	Helical Accelerating Flow Pattern
ITEM 12	Shows	Shape of Vortex Internal Nozzle
ITEM 13	Shows	Reverse Tube Outlet
ITEM 14	Shows	Tube Inlet Fuel/Air Stream

FIG 9	Shows	A Radial Cross Section of a Combustion Nozzle with Bottom Water Orifice Outlet Showing:
ITEM 1	Shows	Outer Wall for Water
ITEM 2	Shows	Tangential Inlet Port
ITEM 3	Shows	Peripheral Ducts (Inlet) Air or Fuel
ITEM 4	Shows	Reducing Section
ITEM 5	Shows	Taper Section
ITEM 6	Shows	Combustion Tube Jet
ITEM 7	Shows	Reducing Tube Section
ITEM 8	Shows	Water Orifice
ITEM 9	Shows	Air or Fuel Outlet
ITEM 10	Shows	Outer Wall for Water Cooling
ITEM 11	Shows	Accelerating Helical Flow Pattern
ITEM 12	Shows	Shape of Vortex Internal Nozzle
ITEM 13	Shows	Parallel Tube Section
ITEM 14	Shows	Retaining Section

ITEM 15 Shows Conical Separator Oil or Air Inlet

ITEM 16 Shows Vortex Orifice Shoulder

ITEM 17 Shows Parallel Section

FIG 10 Shows A Radial Cross Section and Diagrammatic Details for the Bottom Section of a Combustion Vortex Nozzle Jet and Central Tube Detailing the Implosion and Combustion Jet Spallation Pressure Effect on the Formation

ITEM 1 Shows Nozzle Jet Body

ITEM 2 Shows Nozzle Chamber

ITEM 3 Shows Combustion Tube Jet

ITEM 4 Shows Multi-Helical Pattern of Water Two Phase Pulse Jet

ITEM 5 Shows Spalling Area of Flame Jet Slide Force Impingement Low Pressure Zone

ITEM 6 Shows Spalling Area of Flame Jet Central

ITEM 7 Shows Spalling and Water Hammer Area

ITEM 8 Shows Spalling and Flow Separation

ITEM 9 Shows Low Pressure Zones with Formation Of Vapour Bubbles

ITEM 10 Shows Outlet Orifice

ITEM 11 Shows Area of Spallation and Erosion

ITEM 12 Shows Grain Structure in Formation Rock by Spallation

ITEM 13 Shows Shock Diamonds due to Supersonic Jet Velocity of the Flame Itself

FIG 12 Shows Tangential Velocity Profile in Cyclone

ITEM (A) Shows Central Core Air or Oil Outlet

ITEM (B) Shows Water Outlet Contraction

ITEM (C) Shows Outer Vortex Wall

FIG 11 Shows an axial cross section of a spallation head bottom showing

ITEM 1 Shows Spallation head

ITEM 2 Shows Gauge wear pads

ITEM 3 Shows Central spallation jet nozzle

ITEM 4 Shows Outer supercritical water outlet

Fig. 17 shows graph for completed well costs for drilling with linear spallation technology compared to conventional methods in relation to depth of well bore.

Detailed Description of the Preferred Embodiment

The present invention relates to a method of cyclone/vortexing with or without centrifuge chamber, showing a cyclone/vortex internal spinning chamber within a cyclone body allowing a vortex to be induced by either direct drive from the epitrochoidal motor through the drive shaft and bearing pack assembly or by velocity flow through the use of cyclone vortex combustion jet nozzle assemblies fitted either vertically or laterally within the centrifuge spallation drilling head fig. 18 shows a drive shaft driven cyclone vortex spallation jet unit showing:

ITEM 1 Shows Inlet through drive shaft

ITEM 2 Shows Drive shaft from motor

ITEM 3 Shows Seals

ITEM 4 Shows Bearing

ITEM 5 Shows Top sub of housing to drive motor body or nozzle

ITEM 6 Shows Impeller with vertical of lateral blades

ITEM 7 Shows Flow Ducts

ITEM 8 Shows Flow Cone

ITEM 9 Shows Bottom section of vortex/cyclone housing or nozzle

ITEM 10	Shows	Vortex nozzle
ITEM 11	Shows	Inlet flow ports
ITEM 12	Shows	Pin and Box connections
ITEM 13	Shows	Inner cylindrical cyclone shell
ITEM 14	Shows	Air/oil outlet combustion tube
ITEM 15	Shows	Bottom Bearing
ITEM 16	Shows	Bottom seal
ITEM 17	Shows	Outer water wall
ITEM 18	Shows	Air or oil stream
ITEM 19	Shows	Water cyclone orifice
ITEM 20	Shows	Cup type water Outlet
ITEM 21	Shows	Bottom water outlet ports
ITEM 22	Shows	Alternative coaxial outlet one or more
ITEM 23	Shows	Air or oil vortex jet outlet

Fig. 19 shows a velocity driven impeller type top nozzle jet housing for cyclone; vortex body showing:

ITEM 1	Shows	Top nozzle jet body
ITEM 2	Shows	Pin connection
ITEM 3	Shows	Seals (double)
ITEM 4	Shows	Bearing
ITEM 5	Shows	Top bearing impeller
ITEM 6	Shows	Impeller with vertical of lateral blades
ITEM 7	Shows	Impeller central shaft
ITEM 8	Shows	Flow ducts
ITEM 9	Shows	Peripheral velocity inlet port
ITEM 10	Shows	Inlet Chamber

ITEM 11 Shows Flow cone

ITEM 12 Shows Inner Cylindrical Cyclone Shell

Fig. 20 shows a radical cross section of an alternative centrifuge spallation drilling head with flow ports through drive shaft to vortex/cyclone chamber jet nozzles showing spallation drilling head:

ITEM 1 Shows Inlet port

ITEM 2 Shows Spallation drilling head body

ITEM 3 Shows Flow ports to each jet nozzle burner

ITEM 4 Shows Combustion jet nozzle tube outlet

ITEM 5 Shows Water Outlets

ITEM 6 Shows Oil/air, water inlet to nozzles

ITEM 7 Shows Water inlet orifice

ITEM 8 Shows Nozzle body

Fig. 21 shows axial cross section of spallation jet flow port inlets in head of Fig. 20.

Fig. 22 and 23 shows a diagrammatic cross section of a spallation drilling system (A) creating a well bore (B) with spallation drilling head in the area (C) the spallation drilling head is constructed in accordance with the principles of the present invention to produce a supersonic jet spallation action generates a tone comprising of vibrational signals (D) that reflect off of horizons (E) (F) (G) each being respectively deeper in depth than the drilling head (C) the above vibrations or sound waves are then reflected off the horizons back to the surface (H) where sensors such as phones (K) with the data logged there from in Fig. 23 the same cross-sectional elevation is illustrated with the spallation drilling head, having progressed deeper into the well bore (B) past horizon (E) and above horizon (F) at this point the spallation drill head is generating signals (D) which are bounced off only horizons (F) (G)

back to surface (H) the signals (J) are picked up by geophones and recorded as data referring to fig. 24 shows a diagrammatic perspective view of the spallation drilling system (A) spalling a well bore (B) with the drilling system (A) spalling a well bore (B) with the spallation drilling head (C) positioned within the well bore. The spallation drill head (C) produces a very high tone comprised of vibrational signal (D) which bounce off horizon (L) back to the surface. The signals (J) are picked up by the geophones (K) and collected as data at recording station (M) this particular view shows an array of phones that can be set about a drilling operation that will provide for three dimensional perspective interpretation of sub-surface geological data based upon the signals generated and interpreted as seismic signals.

During the spallation drilling operation, it is to note that these signal are generated during the spallation drilling operations to model the formation ahead of the spallation drilling head (C) this promotes safety through detecting horizons that are geo-pressured. The system also allows stratigraphic and structural definitions on a three dimensional perspective from the well bore itself providing significantly enhanced structural and well bore correlation.

Fig. 26 shows a radial cross section of fig. 20 with the same central combustion flame jet nozzle and axial cavitation outer orifice and two outer co-axial water jet orifice ports for well bore diameter drilling control with axial spallation jet nozzles showing:-

ITEM 9	Shows	Co-axial nozzles
ITEM 22	Shows	Co-axial jet ports
ITEM 10	Shows	Axial spallation nozzle orifice

Fig. 27 shows a radial cross-section of a combustion flame jet nozzle with single or multi vortex intensifier combustion chamber to expand the mixture to supersonic velocity in each of the combustion chambers by chamber reduction and nozzle outlets by shock action of the discharging hot products of combustion producing a supersonic combustion flame jet to be directed against the rock surface, showing also an alternative top conical inlet. Central stream

duets, with outer sliding expansion tube with thermal rotary seal for use with fig. 8 and 9 or 18 and 28 showing:-

ITEM 1	Shows	Inlet Orifice air, oil and/or abrasive particle
ITEM 2	Shows	Expansion vortex chamber
ITEM 3	Shows	Reduction orifice to expansion intensifier chamber
ITEM 4	Shows	Intensifier Chamber
ITEM 5	Shows	Spallation reduction nozzle orifice supersonic jet
ITEM 6	Shows	Nozzle body
ITEM 7	Shows	Inlet fuel ducts in place of item 1
ITEM 8	Shows	Retaining top thread and air inlet port
ITEM 9	Shows	Conical inlet
ITEM 10	Shows	Top sliding tube
ITEM 11	Shows	Thermal rotary seal

Fig. 28 shows a bottom diagrammatic, cross section of fig. 18 with bottom section of nozzle fig. 27 and water housing with jet outlets for well bore diameter drilling control, showing:-

ITEM 1	Shows	Cyclone body
ITEM 2	Shows	Vortex chamber
ITEM 3	Shows	Vortex swirl cup chamber bottom and water outlet
ITEM 4	Shows	Combustion jet nozzle
ITEM 5	Shows	Jet nozzle exit orifice
ITEM 6	Shows	Jet nozzle exit tube
ITEM 20	Shows	Fixed water housing
ITEM 22	Shows	Water jets

Fig. 29 shows axial cross section of an umbilical coiled tubing:-

ITEM 1	Shows	Coiled tubing wall

ITEM 2	Shows	First internal small bore coiled tubing for compressed air
ITEM 3	Shows	Second internal small bore oiled tubing for abrasive particles or water and/or abrasives
ITEM 4	Shows	Bore of main coiled tubing for water fuel mixture or water combustion spall returns for low-density flame jet spallation

Fig. 30 shows a longitudinal section of a multi-stacked vortex chamber two stage separation and vortex re-injection for super-critical water and flame jet spallation showing:-

ITEM 1	Shows	Outlet air
ITEM 2	Shows	Outlet water/fuel
ITEM 3	Shows	Inlet port water/fuel/air
ITEM 4	Shows	Electrical cable
ITEM 5	Shows	Storage cylinder fuel
ITEM 6	Shows	Hydrocyclone body
ITEM 7	Shows	Air/water/fuel water droplet atomise control valves
ITEM 8	Shows	Combustion gas sensor for well bore diameter
ITEM 9	Shows	Stand-off sensor
ITEM 10	Shows	Super critical pulse jet
ITEM 11	Shows	Thermal spallation jet
ITEM 12	Shows	Co-axial water outlets
ITEM 13	Shows	Combustion chamber
ITEM 14	Shows	Fuel/air/water control valves
ITEM 15	Shows	Pressurised air chamber
ITEM 16	Shows	Outlet to fuel cylinder

Fig. 31 shows longitudinal section of a coiled tubing umbilical, vortex/cyclone with single stage air separation and re-injection system showing:

ITEM 1	Shows	Outlet port air
ITEM 2	Shows	Outlet port water
ITEM 3	Shows	Inlet port air/water
ITEM 4	Shows	Fuel line in
ITEM 5	Shows	Abrasives in
ITEM 6	Shows	Control valves water fuel/air/abrasives
ITEM 7	Shows	Air/water/fuel water droplet atomise control valves
ITEM 8	Shows	Combustion gas sensor
ITEM 9	Shows	Stand-off sensor
ITEM 10	Shows	Super critical thermal jet spallation
ITEM 11	Shows	Super-critical pulse jets
ITEM 12	Shows	Co-axial outlets (water)
ITEM 13	Shows	Combustion chamber

Fig. 32 shows same as above but with fuel first stage separation showing:

ITEM 1	Shows	Fuel outlet
ITEM 2	Shows	Water outlet
ITEM 3	Shows	Inlet port fuel/water
ITEM 4	Shows	Air line inlet
ITEM 5	Shows	Abrasives in
ITEM 6	Shows	Control valves
ITEM 7	Shows	Electrical control cable
ITEM 8	Shows	Combustion gas sensor
ITEM 9	Shows	Stand off sensor
ITEM 10	Shows	Spallation jet
ITEM 11	Shows	Super-critical pulse jet water
ITEM 12	Shows	Co-axial outlets

ITEM 13 Shows Combustion chamber

Fig. 33 shows a longitudinal section of a multi-stacked vortex/cyclone system first stage air separation into an internal combustion and co-axial fuel inlet ducts with external cooling cyclone swirl for super critical water vortexing along with flame jet spallation showing:

ITEM 1 Shows Outlet port air

ITEM 2 Shows Water fuel

ITEM 3 Shows Air control valves

ITEM 4 Shows Fuel/water droplets inlet ducts

ITEM 5 Shows Electrical cable

ITEM 6 Shows Combustion gas sensor

ITEM 7 Shows Stand off sensor

ITEM 8 Shows Thermal jet spallation

ITEM 9 Shows Super-critical pulse jet water spallation

ITEM 10 Shows Co-axial outlets

ITEM 11 Shows Combustion chamber

ITEM 12 Shows Inlet port air/fuel/water

Fig. 34 shows a trajectory control drilling assembly unit as shown in fig. 1 without the epitrochoidal motor, rotary bearing assembly and centrifuge vortex head. Replaced with non-rotating vortex/cyclone multi-stacked separation system as claimed in the first aspect of the invention, but can also be used with a motor and rotary bearing assembly, further shown:-

ITEM 1 Shows Drilling assembly as fig. 1 without bearing assembly motor

ITEM 2 Shows Fixed vortex/cyclone multi-stacked separation system with and/or multiple axial and co-axial. Water outlets with axial spallation flame jets.

Fig. 35 shows a longitudinal section as shown in fig. 33, but with built in back up fuel accumulator system showing:

ITEM 1	Shows	Air outlets from hydrocyclone
ITEM 2	Shows	Water outlets from hydrocyclone
ITEM 3	Shows	Inlet port water/fuel/air
ITEM 4	Shows	Electrical control cable
ITEM 5	Shows	Storage cylinder accumulator
ITEM 6	Shows	Hydrocyclone body
ITEM 7	Shows	Air water injection
ITEM 8	Shows	Combustion gas sensor for well bore diameter control
ITEM 9	Shows	Stand off sensor
ITEM 10	Shows	Super-critical pulse jet
ITEM 11	Shows	Spallation super-critical/flame jet
ITEM 12	Shows	Alternative co-axial water outlets
ITEM 13	Shows	Fuel/air combustion chamber (with optional water inlet)
ITEM 14	Shows	Fuel and air control valves
ITEM 15	Shows	Fuel outlets from hydrocyclones

Fig. 36 shows a radial cross-section as shown in fig. 33 but without back up fuel system, but provided with water, air, fuel continuous drilling accumulator control system.

ITEM 1	Shows	Seals for vortex stacking units
ITEM 2	Shows	Vortex stack unit
ITEM 3	Shows	Electrical cable
ITEM 4	Shows	Connector bolt
ITEM 5	Shows	Compression Ring

Fig. 37 shows a radial cross-section of a water, air, fuel accumulator back up continuous drilling system showing:-

ITEM 1	Shows	Top valve sub
ITEM 2	Shows	Pin and box connections
ITEM 3	Shows	Piston
ITEM 4	Shows	Pin and Box connections
ITEM 5	Shows	Stand by flow port
ITEM 6	Shows	Bottom valve sub
ITEM 7	Shows	Outlet
ITEM 8	Shows	Box thread
ITEM 9	Shows	Electronic servo 2-way control valve
ITEM 10	Shows	Seal
ITEM 11	Shows	Recharge ports
ITEM 12	Shows	Accumulator cylinder
ITEM 13	Shows	Bore
ITEM 14	Shows	Accumulator Body
ITEM 15	Shows	Piston Seals
ITEM 16	Shows	Pressure spring
ITEM 17	Shows	Equalising port
ITEM 18	Shows	Tube seals
ITEM 19	Shows	Pin threat
ITEM 20	Shows	Metal to metal seal
ITEM 21	Shows	Non-Return valve
ITEM 22	Shows	Ball and seat
ITEM 23	Shows	Inlet port
ITEM 24	Shows	Armoured electrical cable

Fig. 38 shows a radial cross-section of a coiled tubing, spallation drilling head showing a coiled tubing connector as described in our co-pending patent 9305449.2

ITEM 1	Shows	Coiled tubing
ITEM 2	Shows	Internal tubing's fuel inlet
ITEM 2a	Shows	Internal tubing air inlet
ITEM 3	Shows	Coiled tubing connection air line
ITEM 4	Shows	Electrical conduit cable an connection
ITEM 5	Shows	Air to water supply line
ITEM 6	Shows	Coiled tubing connection fuel line
ITEM 7	Shows	Thread connection
ITEM 8	Shows	Pin and box threat top sub
ITEM 9	Shows	Electrical cable
ITEM 10	Shows	Spallation head body
ITEM 11	Shows	Fuel inlet cone nozzle
ITEM 12	Shows	Air tube nozzle
ITEM 13	Shows	Tangential inlet swirl chamber
ITEM 14	Shows	Reducing section of cyclone
ITEM 15	Shows	Straight section -cyclone outlet water
ITEM 16	Shows	Air control valve to water vortex
ITEM 17	Shows	Water tangential inlet port
ITEM 18	Shows	Water cooling fed tube
ITEM 19	Shows	Combustion chamber
ITEM 20	Shows	Cooling water outlet jets to cool gas/spall
ITEM 21	Shows	Cooling water outer chamber
ITEM 22	Shows	Spallation flame jet outlet
ITEM 23	Shows	Vortex water outlet (supercritical heat flux)
ITEM 24	Shows	Sensor well bore diameter

ITEM 25	Shows	Sensor penetration stand off
ITEM 26	Shows	Coiled tubing flared end connector
ITEM 27	Shows	Flared end connector spallation head
ITEM 28	Shows	Insert compression ring
ITEM 29	Shows	Segment type compression coupling
ITEM 30	Shows	Coupling segment retaining bolts
ITEM 31	Shows	Top sub spallation head
ITEM 32	Shows	Combustion insert assembly

Fig. 39 shows a radial cross-section of a combustion chamber vortex intensifier showing:-

ITEM 1	Shows	Air inlet
ITEM 2	Shows	Fuel inlet
ITEM 3	Shows	Combustion chamber body
ITEM 4	Shows	Subsonic swirl and reducing chamber
ITEM 5	Shows	Supersonic flow port
ITEM 6	Shows	Subsonic expansion chamber
ITEM 7	Shows	Supersonic outlet jet orifice

Fig. 40 shows a radial cross-section of a combustion chamber showing:-

ITEM 1	Shows	Inlet fuel port
ITEM 2	Shows	Inlet air port
ITEM 3	Shows	Combustion chamber body
ITEM 4	Shows	Combustion chamber
ITEM 5	Shows	Supersonic jet orifice

Fig. 41 shows a graph of submerged combustion flame (thermal) jets.

Fig. 42 shows diagrammatic drawing of a velocity string and burner head used in spallation drilling.

ITEM 1 Shows Outer Annulus

ITEM 2 Shows Central Flow

ITEM 3 Shows Spallation Head

Fig. 43 shows a radial cross section of a modified spallation combustion burner unit with water and concentrated fuel/water nozzles and optional side combustion injection ports, with cooling water and well bore water control.

ITEM 1 Shows Burner body made of round tubular sections (but not shown)

ITEM 2 Shows Orifice water cooled nozzle

ITEM 3 Shows End retainer ring protector

ITEM 4 Shows Wellbore cooling water outlet ports

ITEM 5 Shows Pulse (low density jet nozzles)

ITEM 6 Shows Burner body cooling water inlet annulus

ITEM 7 Shows Water, fuel, hydrocyclone separation system inlet

ITEM 8 Shows Thermocouple hole

ITEM 9 Shows Slip seals for injector tubes

ITEM 10 Shows Coiled tubing outer (water/kerosine mixture) passage

ITEM 11 Shows Coiled tubing inner compressed air passage

ITEM 12 Shows Fuel water atomising jet

ITEM 13 Shows Electrical line

ITEM 14 Shows Pin and box thread connections for coiled tubing

ITEM 15 Shows Spallation supercritical/flame orifice outlet

Fig. 44 shows multi-coiled tubing types with electrical cable for spallation drilling.

ITEM 1 Shows Outer wall (tubing)

ITEM 2	Shows	Inner wall (tubing)
ITEM 3	Shows	Electrical cable
ITEM 4	Shows	Central wall (tubing)
ITEM 5	Shows	Second wall (tubing)
ITEM 6	Shows	First wall (tubing)
ITEM 7	Shows	Inner tubing bore
ITEM 8	Shows	Centre tubing bore
ITEM 9	Shows	Outer tubing bore
ITEM 10	Shows	Third wall tubing

Fig. 45 shows a diagrammatic drawing of a spallation drilling head and well bore spalling action.

ITEM 1	Shows	Cooling water jets
ITEM 2	Shows	Pulse Jet orifice
ITEM 3	Shows	Vapour bubbles supercritical carries with the jet down to the bottom hole rock surface
ITEM 4	Shows	Area of pulse jet impingement to thermal spallation jet
ITEM 5	Shows	Low pressure zones with formation of vapour bubbles with flow separation on high press mud or water flow on exit path from pulse jet nozzle
ITEM 6	Shows	Erosion of formation by pulse jet (water hammer)

Fig. 46 shows a diagrammatic drawing of a spallation coiled tubing drilling system also used for tunnelling in the horizontal position or micro-tunnelling.

ITEM 1	Shows	internal coiled tubing
ITEM 2	Shows	Well bore
ITEM 3	Shows	Outer coiled tubing

ITEM 4	Shows	Directional control spallation drilling head
ITEM 5	Shows	Thermal spallation jet
ITEM 6	Shows	Well bore bottom

Fig. 47 shows a diagrammatic drawing of a well bore with spallation head showing spalling and spall gas returns with water cooling well bore size.

Fig. 48 and 48a shows a diagrammatic drawing of storage caverns, cavity and shaft formation.

ITEM 1	Shows	First stage of shaft and cavity formation
ITEM 2/3/4	Shows	Steps in forming caverns

Fig. 49 shows a radial cross section of a velocity vent, annulus thermal jet spallation drilling burner head for rotary or stationary use, showing:

ITEM 1	Shows	Outer tubing or casing
ITEM 2	Shows	Inner returns reversal velocity vent tubing or casing
ITEM 3	Shows	Annulus for compressed air (utilities)
ITEM 4	Shows	Water/fuel lines (utilities)
ITEM 5	Shows	Water/fuel lines (utilities)
ITEM 6	Shows	Electrical control line
ITEM 7	Shows	Vortex separation system
ITEM 8	Shows	Manifold
ITEM 9	Shows	Exothermal ignition jet ports
ITEM 10	Shows	Control valves
ITEM 11	Shows	Water cooling ports (inlet)
ITEM 12	Shows	Pulse jet system and ports
ITEM 13	Shows	Orifice jet cooling ports

ITEM 14	Shows	Annular thermal combustion nozzle
ITEM 15	Shows	Annular combustion chamber
ITEM 16	Shows	Water cooling ports (returns)
ITEM 17	Shows	Spray injection (water) combustion
ITEM 18	Shows	Fuel/water/air unit combustion injector spray
ITEM 19	Shows	Thermocoupler
ITEM 20	Shows	Shock diamonds
ITEM 21	Shows	Gas, supercritical H_20 flow
ITEM 22	Shows	Pulse jets
ITEM 23	Shows	Adapter block (tube expansion system)
ITEM 24	Shows	Combustion chamber body
ITEM 25	Shows	Nozzle cooling ports

Fig. 50 shows a axial cross section of a modified combustion thermal jet spallation head with a gas liquid hydrocyclone separation system for ultra deep drilling, showing:-

ITEM 1	Shows	Nozzle with copper face and stellite port
ITEM 2	Shows	Water cooled nozzle
ITEM 3	Shows	Cooling water passages
ITEM 4	Shows	Air jets
ITEM 5	Shows	Fuel mixture jet
ITEM 6	Shows	Cooling water line
ITEM 7	Shows	Cooling water to well bore
ITEM 8	Shows	Air/fuel/water swirl generator separation system
ITEM 9	Shows	Tool joint coupling
ITEM 10	Shows	Armoured electrical cable
ITEM 11	Shows	Accumulator system
ITEM 12	Shows	Hydrocyclone

ITEM 13	Shows	Position for trajectory control units
ITEM 14	Shows	Gas liquid injection expansion manifold top section
ITEM 15	Shows	Air ports
ITEM 16	Shows	Super-critical thermal spallation chamber
ITEM 17	Shows	Atomised fuel/water/air droplets exothermal combustion
ITEM 18	Shows	Supersonic super-critical thermal spallation jet 400°C to 1,800°C
	a)	Air/kerosine/water mixture
	b)	Compressed air
	c)	Kerosine
	d)	Water
	e)	Kerosine/water mixture
ITEM 24	Shows	Fuel passage to water atomiser unit
ITEM 25	Shows	Control valves
ITEM 26	Shows	Vortex exothermic chamber
ITEM 27	Shows	Seals
ITEM 28	Shows	Air (gas) take off - mesh/perforated tube
ITEM 29	Shows	Electrical cable to control valves and instruments
ITEM 30	Shows	Vortex mixture valve control expansion manifold bottom section

Fig. 51 shows an ultra deep downhole gas, liquid swirl generator and hydrocyclone separator with accumulator for kerosine storage showing:-

ITEM 1	Shows	Separator body
ITEM 2	Shows	Inlet bore
ITEM 3	Shows	Kerosine, water, air mixture
ITEM 4	Shows	Swirl type generator
ITEM 5	Shows	Internal air tube
ITEM 6	Shows	Mesh/Perforations in tube (Air take off)

ITEM 7	Shows	Mesh de-mister
ITEM 8	Shows	Liquid take off
ITEM 9	Shows	Swirl plate
ITEM 10	Shows	Liquid take off
ITEM 11	Shows	Kerosine accumulator
ITEM 12	Shows	Water drain
ITEM 13	Shows	Fuel line outlet
ITEM 14	Shows	Fuel line
ITEM 15	Shows	Water Drain from accumulator
ITEM 16	Shows	Fuel inlet to accumulator from hydrocyclone outlet
ITEM 17	Shows	Air tube feed line
ITEM 18	Shows	Water outlet from hydrocyclone
ITEM 19	Shows	Fuel (kerosine) tube feed line water
ITEM 20	Shows	Control valves

Fig. 52 shows a axial cross section of a vortex jet section of the central manifold body for atomising the water and exothermic heat of combustion by air/kerosine (fuel) mixture showing:-

ITEM 1	Shows	Vortex jet manifold valve body
ITEM 2	Shows	Valve control inlet port compressed air
ITEM 3	Shows	Valve control inlet port kerosine) fuel)
ITEM 4	Shows	Valve control inlet port water
ITEM 5	Shows	Swirl chamber water
ITEM 6	Shows	Vortex swirl finder section
ITEM 7	Shows	Air jets for atomising water
ITEM 8	Shows	Atomised water vortex tube
ITEM 9	Shows	Atomised water jet

ITEM 10 Shows Swirl chamber kerosine (fuel)

ITEM 11 Shows Vortex swirl finder section

ITEM 12 Shows Kerosine (fuel) vortex tube

ITEM 13 Shows Kerosine jet

ITEM 14 Shows Swirl chamber air

ITEM 15 Shows Friction air jets

ITEM 16 Shows Vortex swirl finder section

ITEM 17 Shows Vortex swirl outlet to combustion chamber

ITEM 18 Shows First stage air flow jets

ITEM 19 Shows Second stage air flow jets (friction)

ITEM 20 Shows First stage swirl chamber

ITEM 21 Shows Second stage swirl chamber

ITEM 22 Shows Third stage swirl chamber

ITEM 23 Shows Air passage ports

Fig. 53 shows a axial cross section of a ultra deep downhole gas, liquid external type swirl generator angle blades and hydrocyclone separator with accumulator for kerosine storage showing:-

ITEM 1 Shows Separator body

ITEM 2 Shows Inlet bore

ITEM 3 Shows Kerosine, water, air mixture

ITEM 4 Shows External swirl generator with curved stationary blades to swirl the liquid

ITEM 5 Shows Internal air tube

ITEM 6 Shows Mesh/Perforations in tube (Air take off)

ITEM 7 Shows Mesh de-mister

ITEM 8 Shows Liquid take off

ITEM 9 Shows Vortex containment baffle plate

ITEM 10	Shows	Liquid take off
ITEM 11	Shows	Kerosine accumulator
ITEM 12	Shows	Water drain
ITEM 13	Shows	Fuel line outlet
ITEM 14	Shows	Fuel line
ITEM 15	Shows	Water Drain from accumulator
ITEM 16	Shows	Fuel inlet to accumulator from hydrocyclone outlet
ITEM 17	Shows	Air tube feed line
ITEM 18	Shows	Water outlet from hydrocyclone
ITEM 19	Shows	Fuel (kerosine) tube feed line water
ITEM 20	Shows	Control valves
ITEM 21	Shows	Controlled centrifugal swirl of liquid (water-air-kerosine) or (drilling mud-air-kerosine)

Fig. 54 shows axial cross section of a alternative layout for a hydrocyclone separation system for twin coiled tubing.

ITEM 1	Shows	Separator body
ITEM 2	Shows	Outer coiled tubing
ITEM 3	Shows	Inner coiled tubing
ITEM 4	Shows	Water receiver
ITEM 5	Shows	Water passage
ITEM 6	Shows	Hydrocyclone
ITEM 7	Shows	Kerosine accumulator
ITEM 8	Shows	Air passage
ITEM 9	Shows	Kerosine passage
ITEM 10	Shows	Segment off the air line at the hydrocyclone
ITEM 11	Shows	Water lines

ITEM 12 Shows Air passage

Centrifuge, multi vortex combustion jet lateral drilling with spallation technology decreased drilling cost drastically. Drilling costs will be minimal, efficiency will be high, capital costs low and environmentally good with high capital returns

A. Low cost drilling fluid (water, air, fuel) (with abrasive particles if required)

B. No costly drilling bits

C. Minimum weight on penetrator drilling head, no drill collars or drilling tools

D. No rotary drilling, less mechanical drill string damage

E. Less fuel and energy used to drill to equivalent depths

F. No restrictions on depths

G. No restriction on temperature

H. Minimum amount of time to drill to equivalent depths

I. Penetration rates and drilling head life drastically increases over rotary drilling

J. Less drilling time, lower drilling costs, see fig 17, linear drilling technology

K. No expensive down hole and mud motors

L. No bumper subs or drilling jars

M. No Environmental problems in disposing of drilling waste or cuttings

N. Minimum Amount of fishing tools

O. Lower labour cost

P. Enabling more wells to be drilled at lower capital cost

Q. Enabling coiled tubing units to be used to drill deep wells also when drilling under pressure/under balanced

R. Enables long reach horizontal drilling to used at lower capital costs

S. Enables high angle lateral and horizontal wells to be drilled in HDR and geothermal systems

T. Enables most well bores to be drilled with one or more penetrator spallation drilling

heads

U. Allows conventional or slim hole well bores to be drilling at minimal capital cost

V. Allows for spallation drilling heads to be used as hole openers and under reamers

W. No mechanical drill cutting (allows linear drilling and trajectory to be achieved)

X. Ideal for creating caverns and chambers down hole

Y. Ideal for producing oil shale (kerogen rock) production with caverns and micro tunnels at low capital cost

ULTRADEEP SUPER CRITICAL STEAM AND ALTERNATING STEAM/SUPER HOT WATER PRESSURE DRIVE

Summary of the Fourth Aspect of the Inventions

Oil men have realised for a long time that they could not recover all of the oil in place at a reasonable cost. Tremendous cost and environmental advantages are possible with the use of our super-critical thermal combustion spallation drilling system described earlier in the patent. This makes possible the use of ultra deep super-critical hot dry rock stored energy and other types of drilling and mining operation. Reference is made to co-pending PCT application PCT/GB94/00515 and the British Patent Applications from which it claims priority. Those applications describe the concepts of Ultra-deep Crude Technology (UCT), Hot Dry Rock (HDR) Enhanced Oil Recovery (EOR).

The main method of enhancement to primary recovery is water-flood used as a natural drive within the oil reservoir. Used this way, it is more an enhancement to primary recovery than to a secondary recovery method. Steam is used for all types of oil recovery, more so for heavy oils. Steams injection (huff and puff) cyclic steam and steam drive method. The cost of producing generated steam at the surface is a very costly field production expense.

Drilling deep HDR wells for temperature above 450°C, for surface temperatures of about 380°C. HDR super heated water (super critical) with its high flow rates and minimum heat loss can be transported under high pressure far more efficiently through production casing, surface infrastructure, pipe lines and reinjection tubing, alternatively, there is direct injection from the HDR reservoir. Surface generated steam can produce up to 80 percent quality steam up to 95 percent quality steam but not in the same volume as HDR super heated water that can be converted to steam where it is most effective at the well head by alternating choke control to the injection wells, in the formation for thermal two phase flow vapour and oil production. This also allows the quality of the steam to be enhanced at a second stage within the formation by open choke control flow at the production well head.

The use of the UCT-HDR-EOR method, in conjunction with alternating choke controlled pressure cycles, will allow for pressure interface changes in the reservoir which, in turn, allows for steam to form (choke) within the colder front, particularly when the pressure is reduced in the reservoir as shown in Fig. 1'. This lets the hot water drive from the HDR reservoir to form a continuous steam drive, like a reverse cyclic steam system allowing for maximum oil production, with the possible use of fracturing agents to fracture the oil reservoir direct from the HDR reservoir into the oil reservoir from underground or from the surface to allow for high permeability. This allows for direct fracturing control of the complete oil formation, allowing vast cost savings in outside, third party, fracturing cost.

The invention method allows for entire gas or oil burning cost savings, for producing steam at the wellhead and also the associated water cleaning costs will also be a large cost saving. On the plus side any electricity that can be produced by hot water/heat transfer from the HDR system at very low field costs per Kw hour due to the large flow rates through this UCT-HDR-EOR method. By products of clean water and distilled water are also produced within the formation water over production, allowing for increased field profits.

Super-critical temperature and critical pressure of the water (geofluid) causes, mineral silica SiO_2 dissolution, it is likely that some particles will be transported to the ultimate deposition of the HDR reservoir boundary, subject to sorting into different fractions of size and density. Silica SiO_2 is removed by solution and precipitated out of the rocks and transported to the boundary with other minerals grains by material compaction, drilling to super-critical temperature depths is only possible with my spallation drilling system invention.

Silica dissolution at super-critical temperatures and critical pressure is separated out by hydrocyclones, prior to re-injection in to the petroleum formation and pH water levels from the HDR reservoir are never over eight (8), clay swelling is no longer a problem with low pH from the HDR reservoir as pH levels are normally about five (6) to seven (7), this stops destabilisation of the reservoir structure and migration of clay particles and stops bridging and

plugging of the pore thoats. Not only are expandable clay minerals a concern, but problems of increased cleavage or slaking reactions of non-swelling clays occur as water becomes more alkaline, therefore, even in formations that contain only illite and kaolinite, a reduction in permeability can occur.

Injecting cold water down the injector well there will be a rise in temperature above super-critical 374°C until it reaches equilibrium, as the pressure rises past the critical pressure the silica, quartz (SiO_2 in H_2O) comes out of solution metal stable. The production well bores at the well head can also accommodate vortex centrifuge/hydrocyclones to separate the silica out that will produce good quality commercial silica. Then the geofluid is expanded back to a lower temperature and pressure through chokes to be injected into the oil reservoir or heat exchanger, turbines eliminating any silica build up on turbine blades and equipment.

The use of steam in oil formations and the quantity of oil distilled and the rock matrix should be prime considerations, as they determine the incremental production due to steam distillation drive and the matrix surface area that contacts the distillable volume of crude oil.

Crude oil is a mixture of hydrocarbons, organic non-distillable components, inorganic components. heavy metals other minor constituents. The various methods of recovery from oil formation reservoirs range from carbon dioxide to steam at varying temperatures and pressures depending on the depths from which the crude is to be recovered. Generated steam is probably the most widely used method recovering oil.

During recovery of oil by steam, a quantity of the oil may be vaporised, and the movement of this vaporised fraction provides an efficient mechanism whereby additional oil recovered. The effect of pressure and temperature on oil vaporisation, with the use of super-critical steam drive and flood injection HDR systems, equilibrium between liquid and vapour which exists in the oil bearing reservoir contacted by steam.

This is very important within the HDR closed loop system, that allows re-injection of light fraction hydro-carbons all in solution with high pressure super heated steam would undoubtedly increase petroleum recovery.

The Invention Hot Water/Steam, CO_2 Closed Loop HDR-EOR Drive System

Suggested Approach for all API Gravity Oils

How do you revive old oil wells or heterogeneous reservoirs and ensure cost effective operations. while achieving maximum production profit return?

You can now realise the re-opening of abandoned wells/reservoirs, without any environmental disturbance, while assuring minimised operational costs and maximised production profits, by using The Invention patented method.

(a) Drilling into igneous granite or metamorphic rock at depth, and with a rock temperature of about 175°C @ 14,335 ft with a fluid temperature loss to surface and re-injection of 20°C -25°C (40°C/Km depth).

(b) The HDR working fluid is pressurised water with 10% by weight CO_2 (this is about 1/3 the amount of dissolved gas that could be carried into HDR reservoir with surface injection pressure of 3,000 psi), equivalent of 13,200 M^3D flow rate.

(c) The downhole HDR reservoir production pressure should be maintained at a value such that super-critical CO_2 is just ready to start breaking out of solution under these conditions (175°C and 4,200 psi).

(d) At the assumed hydrocarbon reservoir depth of 1,509 ft from the surface the geofluid would have cooled a maximum of 25°C and would be about 75% super-critical CO_2 by volume at a pressure of about 3,200 psi.

(e) At this point, the geofluid would be throttled to an appropriate reservoir inlet pressure of 1,000 psi. The geofluid would now be over 85% CO_2 by volume, with a small fraction of steam and the rest hot water at 150°C. This gaseous slurry will provide an ideal sweep fluid, providing both a significant heat input and a pressurised CO_2/water/steam drive.

(f) The environmental advantage is that residual fluids could be re-injected into the HDR

reservoir, this is because the system is operated in a closed loop fashion, and in turn this would have an economic advantage as well particularly when re-injecting of light-fraction hydrocarbons and carbon dioxide, all in solution and in high pressure water this <u>would undoubtedly increase petroleum recovery</u>

(g) CO_2 is also produced by the HDR reservoir at about 1% by weight of volume, all CO_2 will be separated out by the surface plant for re-injection in the closed loop system.

(h) This unique UCT-HDR-EOR Thermal/CO_2 closed loop pressurised production method would undoubtedly save all of the natural gas, water treatment, water disposal and the enormous plant costs normally encountered by the generated steam method.

(i) The shallower drilling depths would have tremendous savings on the overall drilling and production costs.

(j) Spallation drilling would bring down the cost of drilling due to the increased speed of penetration, meaning the rig would spend less than half of its normal drilling time on station offshore, this would be a tremendous cost saving when drilling.

Super Critical/Choke and Alternating Steam Drive

The stated method will allow up to 95% quality steam with a maximum volume expansion ratio and high enthalpy BTU's/#lb. This is achieved by the formation by alternating high pressure and low pressure cycles; a total gas or crude oil burning saving can be achieved by this method. The main reason is because no surface steam gene rating equipment need be used, which in turn will lead to a total water cleaning cost savings.

The method works like a reverse huff-puff (cyclic steaming) using the super heated hot water to retain its heat under pressure as the driving fluid. The fluid with light hydrocarbon fractions in solutions will, together with the pressurised hot water in a closed-loop-system, increase the rate of petroleum recovery. The added advantage of this system is being able to use the high pressure injection pumps as the formation fracturing pumps.

The super hot water high pressure fracturing of the oil formation can take place where

the porosity and oil saturation can best be stimulated by hot water hydraulic pressure fracturing. The viscosity decreases rapidly with high temperature, which then makes the rock more permeable with a maximum volume expansion of the steam formation (internal energy) within the fractures.

The fractures are opened by the hot water being alternated with high and low pressure pump controllers. The continuing fracturing acts as a driving force (specific volume) treatment for low permeability reservoirs. This will increase the fracture conductivity and allow a flow through the fractured rocks for an optimal completion. This can designed to maximise recovery within the oil formation. In the case of a closed-loop UCT-HDR-EOR system no further artificial lifting equipment (down-hole pumps) will be needed to bring the oil to the surface. This is because the pressure in some reservoirs will allow it to flow in some formation as shown in Figure 2.

A common problem with steam drive projects is that the high temperature (low density) steam tends to rise to the top of the reservoir. This inevitably happens when the steam channels through the high permeability zones and leaves uncontacted high oil saturation portions in the oil reservoir. In the case of Turbidity reservoirs they often have many layers of unconsolidated productive sand, separated by laterally extensive shales. Therefore the importance of maintaining vertical conformance among layers is critical. The formation of steam fonts by controlling the input pressure via the (HDR reservoir) to the oil formation will allow for equal permeability throughout the oil formation will stop channelling thus improving sweep efficiency.

(UCT) HDR Super Hot Water/Alternating-Choked steam at high pressures is known to reduce gas fingering, improve vertical sweep and thereby increase recovery efficiency, eliminating steam breakthrough in heavy oil steam floods.

Choking the output flow to a pressure greater than the calculated compaction pressure would produce greater flow through the higher permeability zone near the well-bore, this can only work with sustained injection in to the dilated reservoir (steam flood) system i.e. if the

temperature of the produced water/oil is 160° and it is expanded to 15 psi, on an open choke alternating control system, the quality of the steam would be 11.3%, or a choke pressure of 500 psi and a field pressure of 800 psi, the quality of the steam produced would be 8% aiding the two-phase production flow.

With the use of Vortex, Cyclone and Centrifuge in Spallation Linear Drilling Technology, it is now possible to drill deeper much faster than conventional drilling, allowing for HDR reservoirs to be fractured and interconnected by drilling pathways within the reservoir to produce high temperatures in the super-critical and critical pressure range, (see Graph Fig. and tables 7, 8, 9, 10, 12, 13), this allows the super critical fluid flow to be transported under pressure, as a single phase fluid, to be expanded back to high quality steam at the production (HDR) wellhead (or downhole) for distribution. Total silica deposition is also possible within the HDR geofluid flow, at these super-critical temperatures. Depositing silica to the boundaries to seal the HDR reservoir.

Planning and Drilling the UCT-HDR Well Bores

Controlling steam temperatures and quality within the formation is achieved by pressures within HDR steam producing wells, this allows for maximum fluid (water) temperature with full enthalpy control. The effect of this fluid (water) control is to control quartz dissolution, particularly as SiO_2 silica dissolution and related problems are most severs in cyclic operations where steam is injected and the well is produced. The dislodged sand will cause a sand control problem, which is usually two-fold: silica is being dislodged with calcite and dolomite: and clays are being released to move and decrease permeability. This method allows for the injection of super heated water/steam just below the formation fracture pressure for normal production, and high pressures for fracturing. The produced hot crude oil (geofluid) is pressured to the surface well head and separated. The returning geofluid is then used to produce electrical generated power before being reinjected back down the injection HDR well in the closed-loop system, or by the extraction of pressure energy prior to

injection.

The satellite well spacing from the central injector can be spaced further apart than the suggested 400 metres. This will depend on the length of the lateral extensions from the main well bore and the inclination of the well itself. These are side track extensions that are drilled in each of the production wells. This will force the fluid on a circuitous path. Most of the reservoir impedance and pressure drop occurs near the production wells, due to pressure dependence of the joint opening of the two or more lateral well bores. The problem will give good correlation with the joint openings and keep the joints open near the production wells.

This in turn allows the injection pressure to be raised in the reservoir to open the joints and likewise reduce the impedance which normally blocks the geofluid from flowing outside the reservoir periphery. To prevent growth in the HDR reservoir under high pressure injection conditions and to only allow for a maximum heat removal rate; the controls will have to match the conductive rate from the reservoir rock.

The use of (UCT) HDR triple trilateral or quadrilaterals well bores, applying central injector and satellite producers will allow for a higher injection and production flow rate. The high flow rates will enable the production of high BTU's for direct process steam use and low electricity cost. Cost savings will be well below the cost of normal HDR geothermal, hydrothermal or natural gas and oil power generation plants. This is with the direct use of (UCT) HDR energy process steam (choked) for petroleum recovery. The life of the HDR reservoir is greatly enhanced (lower thermal drawdown) with the reinjection of the greater majority of heat still remaining within the geofluid. The USA power plant utilities and electrical companies competitive price for electrical generation is between .04 cents to .09 cents per kWh. The use of (UCT) HDR high flow rate system at 2,600 GPM flow rate and in medium 40°C/Km depth reservoir at 380°C and above geofluid will produce electricity at a break even cost of less than 0.2 cents per kWh. This does not take in to account the much lower drilling costs experienced with our new thermal combustion spallation drilling system. that produces a much higher penetration rate.

Opening HDR Fracture Paths

The main joint sets which form deep within HDR reservoirs are generally as near vertical as the minimum principle stresses are near horizontal at depth. The injection or production intervals, of HDR wells in these circumstances must be inclined at such an angle to provide good access to natural joints. This is possible with a triple or more well system with trilateral well bores to allow access to a greater natural joint system.

If flat lying shears are present at depth in the igneous or metamorphic not crystalline granite rock mass, the frequency of the orientation of the joints and direction may change from the bore holes. If hybrid fracture stresses will not open when fracturing, then it will be required to open these paths by connecting the joint system and using ultra high pressure with the use of down-hole intensifiers or spallation. This is best achieved by, either singles or multiples, to force open connecting flow path ways (fractures) for minimum impedance within the HDR reservoir.

The permeability of the HDR reservoir can also be increased by chemical leaching to allow for minimum impedance with the reservoir which allows for high water and CO_2, nitrogen and other gas or agents flow. This is obtainable by the maximum use of flow through the tri-laterals, quad-laterals or any combination of radial or lateral well bores within the HDR reservoir from the fractures. With the increasing future use of electrical power for transportation, this will place additional strain on the increasing shortage of electrical generating capacity in the world. With (UCT) HDR geothermal electrical generating power developed and produced at break even costs of U.S. 1.00 Cents per Kwh.

This method makes the most obvious choice for electrical generation, capital cost and production wise, also environmentally more so now with the use of Thermal Combustion Jet Spallation Drilling with the fluid separation system.

The advantage of creating a number if integrated HDR fractured reservoirs would assist in higher flow rates due to less leakage in the reservoir boundaries.

Producing electricity and direct heat energy for enhanced oil production (EOR) from hot, dry rock (HDR) formations deep below the earth's surface (typically 15.000 to 50.000 feet). By recovering the heat from these underground HDR formations ("heat mining"), produced at the surface using an appropriately designed conventional power plant. The electricity can then be used on site or sold to an electric utility. The electricity produced includes the costs of drilling the geothermal wells, stimulating and maintaining and underground reservoir system and the cost of the building and operating the surface power plant. The patented technology which will greatly reduce the cost of drilling geothermal oil and gas wells, (the largest cost), thereby making HDR heat mining a clean, competitive alternative energy source and available to a virtually unlimited world-wide geographic market.

Benefits of HDR Heat Mining

Energy produced from HDR super-critical heat mining, whether direct use of steam heat or electricity, offers significant potential benefits. These benefits include the following:

* HDR geothermal energy exists in large quantities throughout the world. Approximately world-wide estimates of U.S. commercial geothermal resources are in the range of 100 million quads, which represents approximately 17,000 trillion barrels of oil equivalent.
* HDR geothermal resources are readily available compared to fossil fuels. HDR geothermal power plant could be located virtually anywhere world-wide. The major cost variable will be a function of the depth required at that location to reach the required HDR temperature. Generally speaking, the deeper the wells, the greater the cost of drilling, with spallation drilling technology this cost of deep drilling is no longer a major problem.
* The production of crude oil by the re-injection of HDR super-critical steam direct into the producing formation or through choke controllers in the well head, is readily available compared to the burning fossil fuels in steam generators. The tremendous

environmental and economic cost savings are made possible by drilling deep well bores, with thermal combustion jet spallation drilling with swirl generator and hydrocyclone for ultra deep fluid separation.

* The production of electricity from HDR formations involves the circulation of water through the underground rock in a closed loop system. This allows electricity to be generated with little or no adverse environmental impact, compared to conventional power plants which burn fossil fuels or use nuclear power, and hydroelectric.
* Availability of HDR resources will play an important role in reducing world-wide dependence on oil and gas.
* High production (volume) rates are obtainable when transporting single phase fluids through HDR reservoir fractures, production casings and surface lines, in the super-critical temperature and critical pressure range, be expanded back at the well head to two phase flow, through chokes, producing a lower temperature and pressure for re-injection or surface use.

How HDR Heat Mining Works

There is crystalline igneous, or metamorphic (granite) layers in the earth's crust which completely surrounds the earth. This granite layer is relatively hot compared to surface temperatures. In some areas of the world it is close to the surface and in others it is buried below miles of surface formations. The first step in the process of recovering the heat energy from this layer is to drill an injection well into the HDR formation which has very low permeability (e.g. granite) and sufficient temperature (preferably above 374°C super-critical temperature and 3,204 psi critical pressure, the proposed depth for a HDR reservoir with a temperature of 450°C to 500°C. Allowing for heat loss, to surface temperatures of between 380°C to 430°C are obtainable for re-injection or direct electrical energy use). Next, artificial fractures are created and held open in the rock formation using hydraulic stimulation techniques. Once the fracture system is created, two or more production wells with tri-laterals

are drilled into the fracture zone so that they connect the fracture system to the surface.

Water is then circulated under pressure from the surface into the injection well, through the fracture system where it collects heat energy from the hot rock formation, and then to the surface, where the heat energy is used. The cooled water is then re-injected into the injection well starting the cycle over again. The low permeability of the fractured reservoir prevents most of the water from being lost, creating a closed loop system of continuous circulation. Backup water reservoirs on the surface are used to supplement the injection well as necessary to keep the reservoir fully charged with fluid until the reservoir size has stabilised. The heat energy thus collected on the surface may be used directly to heat buildings or for industrial processes re-injected into hydrocarbon formations or to make electricity. The system for mining heat energy from Hot Dry Rock is pollution free, as compared to conventional power plants which create heat energy by burning fossil fuels.

The Invention Technology

The Invention unique patented spallation drilling Technology which will substantially reduce the cost of drilling geothermal wells. Using high pressure super-critical thermal combustion jet spallation down hole, this new design will increase penetration rates in hard rock by several hundred percent. Prototype heads have been tested in the field and laboratories, with very promising results. Recent field tests proved the spallation head has the capability to spall rock when drilling ultra deep wells at rates of penetration far in excess of conventional drill bits, and also revealed the speeds obtained in spalling large caverns.

The Invention Technology will meaningfully reduce the cost of drilling HDR geothermal oil and gas wells, Reducing drilling costs will enable the world-wide geographical market for HDR applications to expand to almost any location, The Invention Technology is in a unique position to be the leader in the development of a commercial HDR geothermal industry through spallation drilling technology.

Steam, Hot Water, Water Assisted Gravity Drainage

Commercialisation of heavy oils & oil sands with use of spallation drilling is now possible by the formation of underground cavern and tunnel network, from under the oil producing formation to produce heavy oil, oil sands (Bitumen) by a network of well bores drilled from the surface through the producing formation in to the bedrock or basement rock, by a series of directionary drilled well bores, vertical horizontal and downwards from the horizontal into the caverns & tunnels, super-critical steam from the HDR system is then injected in to the oil formation allowing the fluids to flow by gravity drainage to the cavity tunnel net work, for storage prior to the produced hot oil, being pressured to the surface without sand. There is no down hole pumping equipment required, in individual well's. A similar system can also be used for lighter crudes of 26° API gravity and above without steam, or with hot water, hot water, hot water/CO_2 or cold water drive for gravity drainage. The pressurised closed loop sweep, soak system is used for returning hot/water and light hydrocarbon fractions all in solution, back to the HDR injection wells the technology can be applied commercially world-wide with extremely high recovery rates, due to technology of the high rates of drilling velocities by The Invention spallation drilling system.

Background of the Invention for Thermally Heated Oil Reservoirs and Gravity Drainage

This invention relates generally to recovering viscous petroleum from petroleum-containing formations. Throughout the world there are several major deposits of high-viscosity crude petroleum in oil sands not recoverable in their natural state through a well by ordinary production methods. In the United States, the major concentration of such deposits are in Alaska 42 billion barrels and Utah, where approximately 30 billion barrels of in-place heavy oil or tar exists. In California, the estimate of in-place heavy oil or viscous crude is 40 billion barrels. By far the largest deposits in the world are in the Province of Alberta, Canada and represent a total in-place resource of almost 3 trillion barrels. The depths range from surface outcropping (from 100 feet to 2000 feet) with our UCT method depth is never a

problem.

To date only small amounts of these deposits has been produced commercially by an in-situ technology. There have been many in- situ well-to-well pilots, all of which used some form of thermal recovery after establishing communication between injector and producer. The displacing or drive mechanism has been steam and combustion.

Viscous petroleum may be recovered from viscous crude oil containing formations such as oil sand deposits in a process by a injection-production program in which first steam is injected and fluids are produced without restriction. The UCT process should be applied to a viscous crude oil formation in which adequate communications exist or in which a communication path is first established. Optimum results are obtained if the closed loop pressurisation of the steam injection program, and the benefits include substantially increased oil recovery efficiency at all values of steam pore volumes injected. The Cold Lake project uses the huff-and-puff single-well method of steam stimulation and has been producing about 100,000 barrels of viscous crude oil per day.

The most difficult problem in any in-situ well-to-well viscous petroleum project is establishing and maintaining communication between injector and producer. In shallow deposits, fracturing to the surface has occurred in a number of pilots so that satisfactory drive pressure could be maintained. In many cases. problems arise from healing of the fracture when the viscous crude oil that had been mobilised through heat cooled as it moved toward the producer the cool crude oil is essentially immobile.

The sand grains are tightly packed in the formation in tar sands deposits but are generally not consolidated. The API gravity of the bituminous petroleum ranges from about 5 to about 10 and the specific gravity at 60°F is from about 1.005 to about 1.028. The viscosity of bituminous crude oil found in tar sand deposits in the Alberta region is in the range of several million centipoise at formation temperature, which is usually about 40°F.

The primary problem in all oil reservoirs is the high pH levels swelling of clays and silica 510 plugging the pore fractures. This is due to the character of the formations, where

effective mobility of fluids may be extremely low, in some formations hydraulically fracturing has been used to establish communication between injectors and producers. This has not met with uniform success. A situation develops in depths, which cannot stand fracturing pressure. By changing the pH level in the Alkaline range, effect a reduction in the interfacial oil/water tension, where by the petroleum and detached from the surface of the pores of the rock and an oil - water emulsion is formed which enhances the effect of displacement and will increase the degree to which the oil is removed from petroleum formation by steam, by lower pH levels in the HDR geofluid and the removal of silica SiO_2 from the super-critical water at critical pressure.

Many processes have been utilised in attempting to recover to viscous crude oil from oil formations. The application of heat to such viscous crude oil formations by steam or underground combustion has been attempted. Clearly, this method will establish and maintain communication between injector and producer, it will open up many viscous heavy oil and tar sands deposits.

Brief Description of the Invention for Oil Mining by Gravity Drainage

The present invention is a method of assisting the recovery of viscous petroleum from a hydrocarbon containing formation and is particularly useful in those formations where communication between an injection position and recovery position is difficult to establish and maintain. A substantially vertical and horizontal passage, such as a well or shaft and tunnel, is formed through the hydrocarbon-containing formation. A closed-loop flow path is provided from the earth's surface through a substantial portion of the formation penetrated by the two vertical and horizontal passage. A recovery path is formed for flowing crude oil out of the formation. This path will be located in the passage at the bottom thereof.

Object of the Invention for Steam Soak or Steam Drive and Thermally Heating their Reservoir by Twin Velocity Heater Casings for Gravity Drainage

The principal object of the present invention is to maximise recovery of viscous hydrocarbon from heavy oil and tar and having a large vertical and horizontal communication between injector position and a producer position to establish and maintain by utilising super-critical hot water and to physically separated out the silica from the water by hydrocyclones due to silica dissolution at super-critical temperature critical pressure. Allowing for substantially increased flow through pores within the reservoir or the super-critical water at critical pressure flowing through the twin velocity heated casings either by heated gravity flow or steam drive principles for flow paths through the formation to assist in establishing and maintaining communication for a drive fluid or thermal heat used to promote movement of the crude oil to the producer position. Further objects and advantages of the present invention will become apparent when the description is read in view of the accompanying drawings which are made a part of this specification.

Optimum results are attained with the use of two or more wells, and it is usually preferable to arrange the wells in some pattern as is well known in the art of oil recovery, such as a five spot pattern in which an injection well is surrounded with four production wells, or in line drive arrangement in which a series of aligned production wells are utilised, for the purpose of improving horizontal sweep efficiency. The formation possesses sufficient initial or naturally occurring permeability that steam and other fluids may be injected into the formation at a satisfactory rate and pass therethrough to spaced apart wells without danger of causing plugging by high pH levels and silica or other flow-obstructing phenomena occurring, the process to be described more fully hereinafter below may be applied without any prior treatment of the formation.

In some instances it is sufficient to inject a gas such as CO_2 and gaseous hydrocarbon fractions with hot water and/or steam all in solution into one well and produce fluids from the remotely located well until mobile liquids present in the formation have been displaced and a

gas swept zone is formed, steam may be injected safely into the previously gas swept zone without danger of plugging the formation. Plugging is thought to occur in the instances of steam injection because viscous hydrocarbons mobilised by the injected steam bank into colder portions of the formations, thereafter cooling and becoming immobile at a point remote from the place in the formation in which steam is being injected, thus preventing further fluid flow through the plugged portion of the formation. The use of velocity return twin casing used in extended reach horizontal wells is made possible by spallation drilling to thermally mobilise the bank of immobile bitumen that has cooled sufficiently to become immobile, subsequent treatment is precluded since steam or other fluids which would be capable of mobilising the bitumen cannot be injected through the plugged portion of the formation to contact the occluding materials, and so that portion of the formation may be subjected to further oil recovery operations. The step of developing well-to-well communications by The Invention twin thermal velocity tubes is an exceedingly important one in this or any other process involving injection of heated fluids such as steam into low permeability tar sands deposits for heating the formation.

The horizontal position of the communication channel can be controlled, such as in the instance of expanding a fractured zone into the communication path between wells, it is preferable that the communication path be located in the lower portion of the formation, at the bottom near the production well bores for fluid flow paths into the slotted liners. This heated mobilised flow of viscous crude oil portion of the formation immediately below the twin velocity tubes, which will drain downward to the heated, high permeability communication path where the viscous crude oil is easily displaced toward the production well. It has been found easier to gravity drain viscous crude oil from the formation located below the communication path than to pump viscous petroleum from the portion of the formation located below the communication path.

The communication path is established by the injection of steam into the twin casings. The maximum pressure and temperature at which steam is to be injected fracture of the

overburden above the formation would occur since the injection pressure is relevant only to casing burst strength capability.

Super-critical superheated steam and critical pressure is used in the process of my invention. The preferred steam quality from 852% to about 952%.

The optimum degree to which the flow of fluids from production wells in to the production caverns by gravity drainage for steam can also be injected into the formation as described earlier in my patent but with the added advantage of not producing any silica prior to separation by hydrocyclones in which one or both methods can be incorporated to maximise crude oil production.

The oil recovery process is continued with repetitive cycles comprising heating, by thermal twin casings or steam drive pressurisation production followed with greatly reduced steam injection rates.

The oil recovery efficiency begins to increase as is detected by a reduction in the oil/water ratio of produced fluids.

The foregoing amply demonstrate that the use of steam injection in the described sequences of steam injection.

The method of directionally drilling twin large bore horizontal wells, by spallation drilling for the injection and production of heavy crude oil or oil sands (bitumen) using the upper injection well, to install a heat pipe exchanger (casing) with a inner concentric velocity tube. The outer tube is used to transport the injected super-critical steam/water under pressure, and returning back through the inner velocity tube, to the well head and surface pipe work back down the HDR injection well, in a closed loop system. The upper heat pipe transfers its pressurised recycled heat to the oil formation, the heat is absorbed, by the formation, through the heat given off by the heat exchanger casing, this allows the total heat energy from the supercritical steam/water to be transferred to the oil formation to thermally mobilising the crude oil, tar sands bitumen in the formation, allowing the hot crude oil to flow into the lower production casing with slotted liners, along its entire horizontal section,

the well bore casing then dips down from the horizontal into the bedrock gravity collection and tunnels to be pressured to the surface, with no sand production, the returning super high temperature, steam/water, still under pressure is then used to produce generated electrical power via a heat exchanger system at the surface to produce the maximum amount of electrical power for field use leaving the bulk of remaining generated electricity to be sold to the local electrical utility company. Making this extremely economical and environmentally sound.

The Embodiment of the Patent

The embodiment of the present invention will now described by example and with reference to accompanying drawings in which:-

Fig 14' shows a 5.6 km well based on a temperature gradient of 75°/km depth with hypothetical pressure profile through a supercritical reservoir.

Fig 15' shows super critical temperature in relation to depth at 66°C and casing/tubing, well head flow temperature at surface.

Fig 16' shows super critical temperature in relation to depth at 5O°C, 75°C and 100°C and casing/tubing, well head flow temperature at surface.

Fig 17' shows temperature and specific gravity at supercritical temperatures.

Fig 18' shows submerged combustion flame jets in relation to depth of well bore.

Figure 2' shows a diagrammatic view of a HDR geothermal reservoir and petroleum formation with a typical example of injection and production well bores.

No more steam generators and water treatment plants: The Invention UCT makes possible increased high recovery rates for medium and heavy oil (bitumen), to revive complex and heterogeneous formations, with super-critical steam from a HDR geothermal reservoir, for re-injection into a hydrocarbon formation showing a typical example of

injection and production well bores. The surface plant layout is shown where super-critical water at critical pressure is brought to the surface and converted to steam at the well head by choke control, prior to re-injection back into the hydrocarbon formation, producing up to 95% high quality steam for two phase flow, enhanced oil recovery (EOR). This ensures maximum production, profit return and environmental control.

The Invention, new Spallation Drilling system, now makes it possible to drill ultra deep wells into crystalline rocks "Onshore & Offshore" for the production of super-critical steam for EOR, electrical power generation, cavity formation and micro tunnelling. Spallation drilling is a true linear drilling system with surface trajectory control, for directional drilling.

1. Water make up line.
2. Pumping plant.
3. Injection well and well head (HDR) 100,000 barrels of water per day @ 6,000 psi.
4. Production well (HDR).
5. Steam injection wells.
6. Crude oil production wells.
7. Production well heads (EOR).
8. (HDR) re-injection well head.
9. (HDR) production well heads super-critical, producing 50,000 barrels per day 380°C @ 3,204 psi.
10. Water, oil, gas separation plant.
11. Electrical generating plant.
12. Hot water line to generating plant.
13. Hot water return line to re-injection pumping plant.
14. Water, gas and light hydrocarbon fraction line from separation plant for re-injection by pumping plant.
15. Crude oil (Geofluid) production line to separation plant.
16. Hydrocarbon formation.

17. Cavities and open hole sections.
18. Production well head flow chokes for expansion in formation for two phase flow with up to 95% quality steam up to 2,500 psi @ 354°C.
19. (HDR) Hot dry rock man made geothermal reservoir.
20. Overburden formation.
21. Petroleum export pipe line.
22. Electrical power lines.
23. Granite crystalline formation.
24. Shows basement storage cavity (can also have natural fractures from oil formation in to cavity).
25. Vertical well to cavity.
26. Slotted liners.
27. Directional wells through reservoir to storage cavity.
28. Horizontal gravity steam injector well.
29. Horizontal gravity production well (optional gravity drainage to storage cavities).
30. Heated oil zone area or alternative sub-critical steam hot water injection with CO_2 pressure drive.
31. Storage of oil & gas.
32. Coiled tubing drilling work over and injector head system.
33. Ultra deep cavities for storage of:
    a) Nuclear waste.
    b) Gas, liquid fuel.
    c) Compressed air for electrical power.
    d) Water.
    e) Chlorinated hydrocarbons.
34. Well head spallation drilling control with down hole casing to form a cavern.
35. Velocity production of spalls with well head and down hole casing.

36. Velocity exhaust pipe to remove spalls when drilling.
37. Shows spallation drilling system down hole for forming ultra deep storage caverns.

Alternative

HDR production wells (item 4) can be side tracked from the vertical by horizontally drilled lateral wells prior to being completed with down-hole packers. The packers are set in the vertical section above the petroleum formation to replace the injector wells (item 5) which are normally used to inject steam from the surface. The production liners are completed with polished bore receptacles with chokes fitted to the down-hole production liners as shown in the diagram Figure 2' and Figure 1'.

Fig. 3' shows two or more hard rock storage caverns for gas or fluid with interconnecting horizontal micro tunnel, showing injection and withdrawal well heads and pipelines showing:

Item 1. Shows well bores and casing (A).

Item 2. Shows well bores and casing (B).

Item 3. Shows hard rock storage caverns (A).

Item 4. Shows hard rock storage caverns (B).

Item 5. Shows well heads.

Item 6. Shows main supply injection and withdrawal pipeline.

Item 7. Shows horizontal connecting micro tunnel.

Item 8. Shows gas compressors.

Item 9. Shows gas heaters.

Item 10. Shows gas Dehydrator.

Item 11. Shows pressure reduction valve.

Item 12. Shows pipe line injection & withdrawal loop.

Figure 4' shows a cross section of the diagrammatic drawing Fig. 11' which shows.

Item 1. Shows steam injector well bores or 1A twin velocity thermal casings.

Item 2. Shows oil production well bores.

Item 3. Shows gravity draining by steam injection or thermal heating.

Item 4. Shows horizontal/directional well bores for gravity drainage to horizontal tunnel.

Item 5. Shows horizontal interconnecting well bore large tunnel.

Item 6. Shows production bore shaft.

Item 7. Shows multi-production casings.

Item 8. Shows oil sands formation.

Item 9. Shows overburden.

Item 10. Shows limestone bedrock.

Item 11. Shows pump house.

Item 12. Shows closed loop pipeline to HDR re-injection.

Item 13. Shows export pipe line.

Item 14. Shows produced oil.

Item 15. Shows basement crystalline rock.

Figure 5' shows cross section of well bore and tunnel, cavity patterns for gravity drainage storage system flow pattern with full explanation details of injection & production cycles.

Item 1. Shows injector wells.

Item 2. Shows production wells.

Item 3. Shows cavities.

Item 4. Shows shaft (bores).

Item 5. Shows tunnels (bores).

Figure 6' and 6'a shows a radial cross sections of a duel-vortex intensifiers cavitation shear/pulse nozzle pack, for multi-jet spallation head further shown are:

Item 1. Shows top vortex swirl chamber.

Item 2. Shows shear areas.

Item 3. Shows accelerating helical flow reducing section.

Item 4. Shows expanding vortex shear chamber intensifier.

Item 5. Shows vortex accelerator cone section.

Item 6. Shows vortex cavitation shear flow exit orifice.

Item 7. Shows accelerating inlet reducing section.

Item 8. Shows inlet port.

Item 9. Shows expanding vortex shear chamber intensifier.

Item 10. Shows nozzle body.

Figure 7', 8', 9', 10, 12' and 13' graphs and tables showing relationship between steam quality and geofluid expansion pressure for sub-critical and super-critical at critical pressure.

Figure 11' shows a diagrammatic view of a method with spallation drilling using shaft tunnels and twin directional well bores to mobilise oil sands bitumen, heavy oil and other crudes by gravity drainage showing:

Item 1. Shows overburden.

Item 2. Shows oil sands formation.

Item 3. Shows limestone (bedrock).

Item 4. Shows crystalline (granite rock)..

Item 5. Shows vertical bore shaft.

Item 6. Shows horizontal bore (cavities) tunnels for gravity oil collection.

Item 7. Shows steam injection well bore with slotted liners.

Item 8. Shows lower horizontal production well bore with slotted liners.

Item 9. Shows vertical well bore with two or more horizontal side track wells.

Item 10. Shows thermal packer system.

Item 11. Shows steam injector well heads.

Item 12. Shows HDR producer well heads.

Item 13. Shows HDR cold water injector well bore.

Item 14. Shows HDR injector well bore.

Item 15. Shows HDR tri-lateral producer wellbores.

Item 16. Shows HDR fractured reservoir.

Item 17. Shows gravity drainage production well bore.

Item 18. Shows pipe line from HDR producers to steam injector well heads.

Item 19. Shows closed loop water/gas return line.

Item 20. Shows make up water line.

Item 21. Shows production high temperature separator/production pump house.

Item 22. Shows export (Bitumen/crude oil) line.

CLAIMS:

1. A tool is claimed for the use of a centrifuge to be used in combustion jet spallation drilling.

2. A tool is claimed for the use of vortex chamber single or multiple, staked above one another vertical or offset if required for high velocity fluid flow, or any combination as shown therein.

3. A method is claimed for the separation of air and oil from water by a centrifuge in spallation drilling.

4. A method is claimed for the separation of air and oil from water by use of a vortex in spallation drilling.

5. A tool is claimed for the use of a epitrochoid tri-rotor motor or turbine or any type of hydraulic motor to drive the centrifuge in combustion jet spallation.

6. A method is claimed for the use of centrifuge and vortex chambers, single or multiple to be used together for combustion jet spallation.

7. A method is claimed for the use of central combustion nozzle jet tube with tangential inlet ports within the vortex chamber for combustion jet spallation drilling.

8. A Tool is claimed for an orientation unit to be used in combustion jet spallation drilling.

9. A Tool is claimed for trajectory control unit for combustion jet spallation drilling.

10. A Method is claimed for the drilling of bore hole vertical, lateral and horizontal by the use of combustion jet multi-vortex centrifuge spallation drilling.

11. A method is claimed by the use if centrifuge and vortex chambers with central nozzle jet tube with tangential flow ports for air and oil separation allowing the centrifugal forces to separate the water, air and oil so the water is used first for cooling purposes and for fluid cavitation to erode the target formation with combustion jet spallation.

12. A method is claimed for the use of coaxial or bottom orifice outlets with any combination of internal jet tube nozzles for separation of oil and compressed air from the water, in centrifuge/vortex spallation drilling units.

13. A method is claimed for the use of coiled tubing with one or two internally fitted flow lines to transport the compressed air and oil or either if only one tube with adapter plate, flow ports and unions is used to the centrifuge spallation drilling head.

14. A method is claimed by the use of central cyclone shell rotating around a fixed outer casing to allow for vortexing by the use of impeller, flow ducts and flow cone driven by a down hole motor or velocity flow by peripheral port onto vertical or lateral impeller blades producing rotation of the cyclone shell.

15. A method is claimed by the use of vortex, cyclone and/or centrifuge in combustion jet spallation drilling to allow for the spalling of a rock formation in deep vertical, lateral and horizontal continuous bore holes.

16. A method is claimed for the formation of ultra large open hole bore hole sections cavities with the use of lateral, horizontal vortex, cyclone and/or centrifuge combustion jet spallation drilling in stable rock formations.

17. A method is claimed for the formation of long horizontal tunnels in rock formation with the use of vortex, cyclone and/or centrifuge combustion jet spallation drilling.

18. A method is claimed for the formation and construction of large diameter vertical shafts, cavities and tunnels with the use of vortex, cyclone and centrifuge combustion jet spallation bore hole mining.

19. A method is claimed for the formation of interconnecting, vertical, lateral and horizontal slim hole bores to minimise flow impedance in rock formation between injection well and producing wells with the use of vortex cyclone and/or centrifuge combustion jet spallation drilling.

20. A method is claimed including the steps of providing a noise detection array for monitoring subsurface noises and generating a tone with the supersonic flow discharge the range of frequencies occurring in the sound emitted by the source from the said vortex, cyclone centrifuge flow through the combustion spallation jet or jets in the spallation drilling head within the well bore.

21. A method is claimed as set forth in 20 including the step of varying the said tone by varying the flow of the fluid flowing through the said spallation drilling head for enhancing the detection of seismic signals by noise detection, detecting the said noise from the spallation drilling head and converting the noise into data.

22. A method is claimed for the use of centrifuge, vortex or cyclone for combustion jet spallation drilling whereby the water, air and oil are used together for separation down hole, where the air and oil are used for spalling formation rock and the water is used for cooling and water-jet cavitation or water hammer effect, for increased spallation and erosion in a fully integrated drilling system with a rotating or non-rotating drilling head.

23. A method is claimed for the use of centrifuge, vortex or cyclone for use in spallation drilling and or cavitation/water hammer erosion or combined rotating or stationary type, single or multi jet nozzles.

24. The method according to claim 1, 2, 3, 4, 19 in which the said body is a mass of soil igneous metamorphic or sedimentary formation, or mineral material.

25. The method according to any claim by adding abrasive particles to the jet streams within the combustion jet nozzles or water vortexing.

26. The method of controlling bore hole size by the use of flame combustion jet for spalling with the use of water for cooling and controlled bore hole size of water nozzle outlets.

27. A method is claimed to open cracks, fractures by allowing the flame jet to pass into the crack opening to enlarge the flow pathways by spalling the rock in all direction with the use of the trajectory drilling control spallation assembly assisting in fracturing tight formations.

28. A method of using any combination of any feature, described herein with reference to Fig. 1 to 34 of the accompanying drawings inclusive, vortex, cyclone and/or centrifuge single or multiple in supersonic combustion flame jet spallation with any combination of

combustion jet nozzle within the nozzle body, and any combination of inlet port into the nozzle, head body along with any combination of water outlets and angles of the outlet ports for fluid cavitation, water hammer erosion and/or well bore diameter drilling control.

29. A method is claimed by the use of multi-stacked swirl generator, hydrocyclone vortex cyclone for air, oil, water, and abrasive particles separation, re-injection control together with electrical down hole control with the use of electrical cable external or internally within coiled tubing for instrumentation and diagnostic control, measurements for:-

1) Air fuel flow rates
2) Well bore distance stand-off
3) Rates of Penetration
4) Lifting capacity for spall/air/water mixture
5) Flame temperature
6) Pressure in combustion chamber
7) Temperature of cooling water, gas and velocity to control well bore diameter and trajectory orientation control.

30. A method is claimed with the use of storage pressure chambers to store down hole air and/or fuel for continual drilling when replacing each stand-off drill pipe, with the use of hydrocyclone vortex, cyclone and/or centrifuge separation methods by maintaining combustion chamber pressure, by flame jet for super critical and super critical spallation.

31. A method is claimed with the use of combustion flame jet spallation in conjunction with the heat flux produced by super critical water exiting and impinging on the axial nozzle orifice to produce a heat transfer process the same spallation intensity as the flame jet to further induce acoustic coupling to transfer energy to the rock in an oscillatory mode that will further enhance rock failure and increase drilling penetration rates.

32. A method is claimed for the use of any type of storage accumulator units to be used for continuous spallation drilling.

33. A method is claimed for the use of fuel and water to be used in a concentrated form for thermal spallation drilling super critical and super critical jet flow.

34. A method is claimed for the use of water to be injected into the combustion chamber for lower temperature flame jets with super critical jet flows.

35. A method is claimed to allow water impingement on to the flame jet within the combustion chamber by small injection orifice ports around the circumference of the bottom end of the combustion chamber.

36. A method is claimed with the use of hydrocyclone vortex of centrifuge separation whereby fuel and water are left in a concentrated fuel mixture on separation or for re-injected water injection into the combustion chamber to permit oxidation whose exothermic heat of combustion will produce a mixture of hot super critical water, nitrogen and carbon dioxide to be expanded as a subsonic jet to produce stagnation heat fluxes of up to 20 MW/m^2, and further into supersonic jet by pressure adjustment to the intensify the pressure drop across the nozzle to a level beyond the critical ratio.

37. A method is claimed for the use of a swirl generator to separate air from fuel and water in spallation drilling.

38. A method is claimed for the use of none return ball, dart or flapper type valves to be placed every 30 feet or more within the drill string for retaining pressure within the drill

string for thermal jet spallation drilling.

39. A method is claimed for the use of a central vortex jet nozzle to swirl the fluid mixture (water & fuel) at high velocity into the external ring of air jets in the vortex chamber, to produce a plume of atomised droplets each containing trapped air bubbles, only a small portion of air feeding into the external nozzle end up in the centre of the liquid mixture like small droplets the rest of the air surrounds the plume.

40. A method substantially as herein before described with reference to the accompanying drawings.

41. A method of fracturing hydrocarbon formations by increasing flow rates by the use of super hot water hydraulic pressure fracturing directly from the geothermal (HDR) reservoir into the oil bearing formation or back to the surface for reinjection.

42. A method of controlling production pressure with choke controllers to form reverse cyclic steam in the oil reservoir for maximum enthalpy down-hole. This method allows efficient transportation of super high temperature hot water steam into the formation by a pressure reduction (choked back) to form a steam front, allowing maximum amounts to be produced down-hole.

43. A method is claimed for the use of hot water CO_2 and light hydrocarbon fractions all in solution to increase oil production with the use of HDR methods.

44. A tool is claimed for the drilling of geothermal (HDR) and hydrocarbon/mineral well-bores by the use of thermal combustion jet spallation drilling system with swirl type generator and hydrocyclone for fluid separation for deep drilling with coiled tubing or standard drill

pipe.

45. A method of controlling HDR super hot water for maximum enthalpy steam expansion by opening and closing the choke controls at the injection wellhead; alternating the down-hole flow pressures. The variable pressure output will lead to a maximum volume expansion in the reservoir. This is achieved when the temperature changes in the reservoir allow for steam fronts to be formed when the pressure is reduced.

46. A method of claimed for the use of a nozzle, for drilling bit hydraulics, with the use of multi-vortex intensifier chambers. The method shows inside flow nozzles for producing low and high pressure zones for flow separation, propagating the destructive stress cavitation of the drilling fluid as it passes through the nozzles. The subsequent breakdown of the rock formation will allow the mechanical action of the drilling bit to penetrate at a much faster rate with a much longer life in conjunction with a spallation drilling head.

47. A method is claimed for drilling bit flow nozzles by the use of dual vortex intensifier chambers for accelerating helical flow, by flow reduction for producing vortex flow cavitation shear pulse at the exit orifice nozzle in conjunction with a spallation drilling head.

48. A method is claimed for the use of ION implantation and ION beam diamond like carbon surface, as an ultra-hard abrasion resistant wear surface within the vortex chambers. Helical flow reducing ports and the exit orifice sharp area, for ultra-long wear life in the spallation drilling head body.

49. A method for continuous ultra high velocity liquid jet, by generating a continuous liquid jet by providing a multi-vortex intensifier type flow nozzle for the thereof, forming a aperture through the said multi-vortex intensifier type flow nozzle for the continuous intermittent

discharge of ultra high velocity liquid jet therefrom to swirl the combustion gases inside the combustion chamber in conjunction with a spallation drilling head to permit a swirling motion to the rock face.

50. A method of cutting a surface with a continuous intermittent ultra high velocity liquid, providing a vortex intensifier type flow nozzle, laterally fitted in to the spallation drilling head body for much improved penetration rates, jet hydraulics and cleaning efficiency for erosion thereof

51. A method is claimed for the use of tunnels, cavities in producing crude oil from formation with well bores for gravity drainage into storage tunnels & cavities by HDR steam injection on a closed loop system.

52. A method is claimed for the use of the (UCT) HDR-EOR method of super hot water injected at high velocity by the use of a horizontal unperforated heating pipe running between a vertical steam injection well and a vertical production well, super high temperature hot water is circulated inside the horizontal pipe, heat is transferred from the hot pipe to the adjacent formation (tar stands) creating a significant annulus of heated formation used on a closed loop (UCT) HDR-EOR system, the hot returning water can be used for converting to steam by choke, to re-inject for steam drive.

53. A method is claimed for the use of energy, maximum amount of BTU's can be delivered at high pressure at about 3,000 psi when super hot water is used, allowing for high velocity/volume flow rates or the returning water can be used for electrical generation with the high amount of enthalpy still within the super hot water.

54. A tool is claimed for the use of vortex chambers single or multiple, stacked above one another vertical or offset if required for high velocity fluid flow or any combination as shown therein for spallation drilling jets & fluid mixing in the spallation manifold.

55. A method is claimed for the separation of air and oil from water by a centrifuge in spallation drilling.

56. A method is claimed for the use of directional drilling in to a oil reservoir, then down in to the basement rock by one or more bore holes (well bores) into a spalled out cavern using spallation drilling for increased production of crude oil from the oil bearing formation the cavern where possible can be close to the oil bearing formation to allow the oil in natural fractures also to flow into the cavern, for extraction.

57. A method is claimed in HDR reservoirs and well bores for the use of super-critical hot above 374°C at 3,204 psi critical pressure, liquid will be transported at maximum volume prior to being expanded back at the surface for re-injection in to the oil reservoir at a lower temperature and pressure.

58. A method is claimed for the use of hydrocyclones first stage separation of silica SiO_2 from super-critical water at critical pressure when pressured to the HDR production wellhead prior to re-injection into the oil formation or for heat extraction for electrical generation.

59. A method is claimed for the use of storage caverns in gravity drainage, by the spalling of rock by spallation drilling head system.

60. A method is claimed for the use of large well bores (shafts) and horizontal bores (tunnels) to be used in the extraction of oil from any type of hydrocarbon (oil) formation.

61. A method is claimed for the spalling of concrete by thermal combustion jet spallation drill head system.

62. A method is claimed for the incineration of toxic waste inside heavy duty offshore-onshore tanks and downhole cavity storage systems.

63. A method is claimed by changing the pH level in the Alkaline range, effect a reduction in the interfacial oil/water tension, where by the petroleum & detached from the surface of the pores of the rock and an oil - water emulsion is formed which enhances the effect of displacement and will increase the degree to which the oil is removed from petroleum formation by steam, by lower pH levels in the HDR geofluid and the removal of silica SiO_2 from the super-critical water at critical pressure.

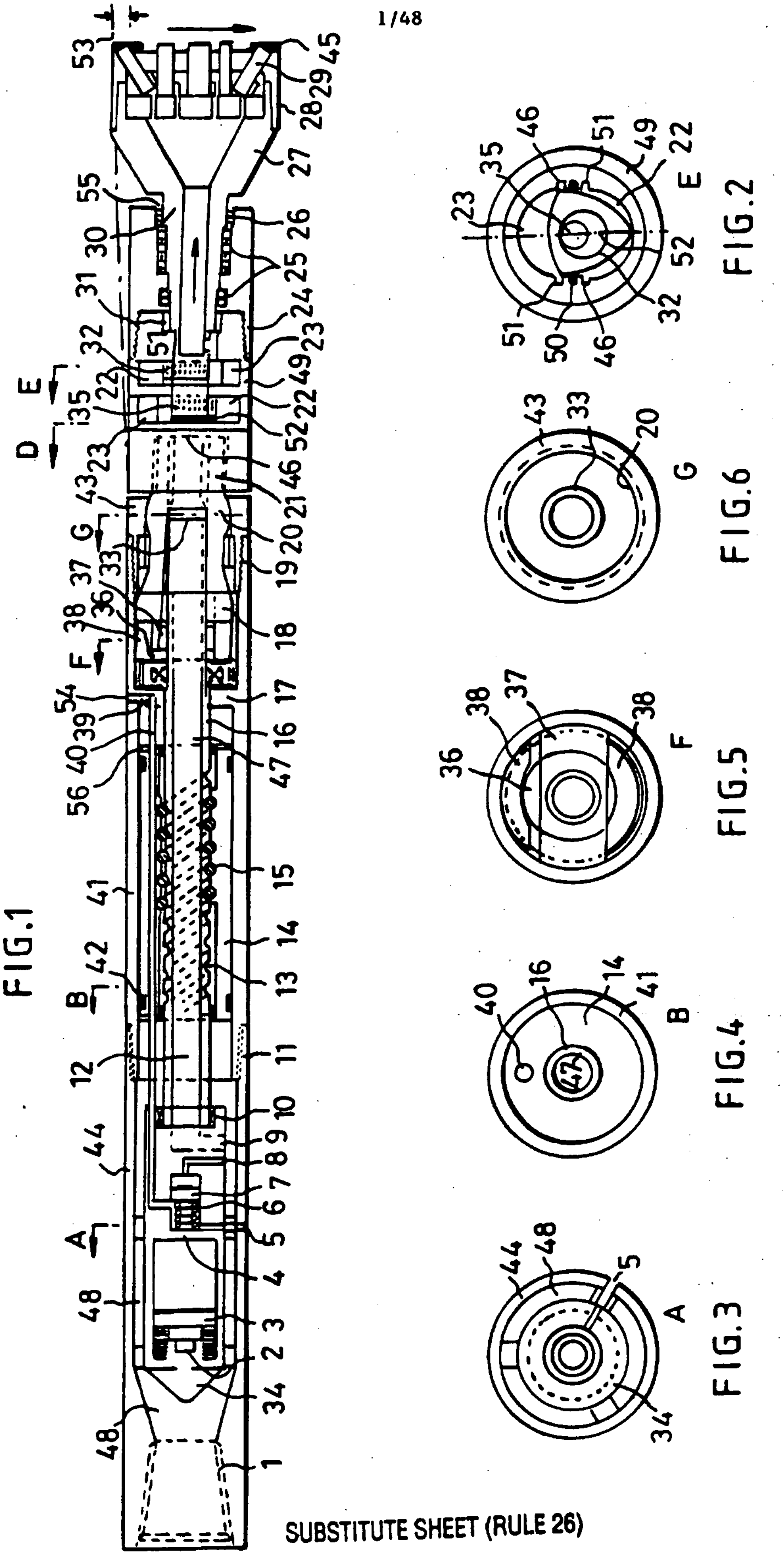


FIG.1

FIG.2

FIG.3

FIG.4

FIG.5

FIG.6

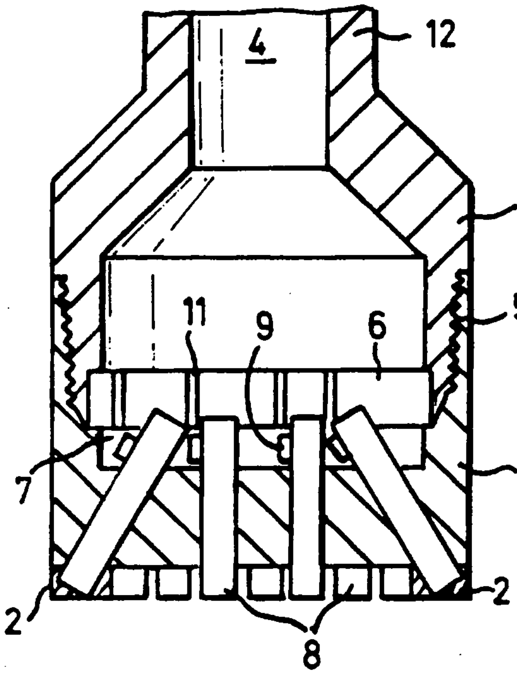


FIG.7

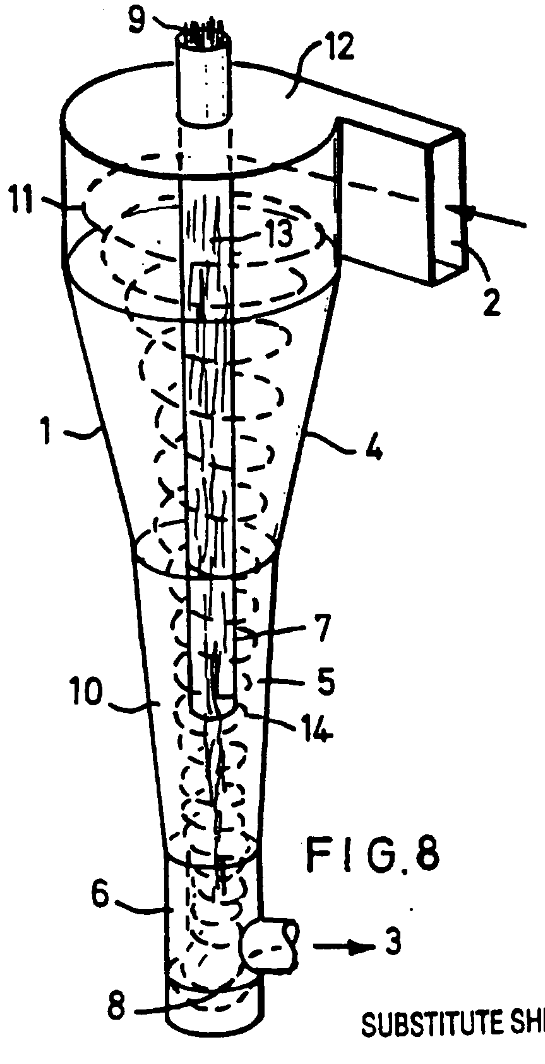


FIG.8

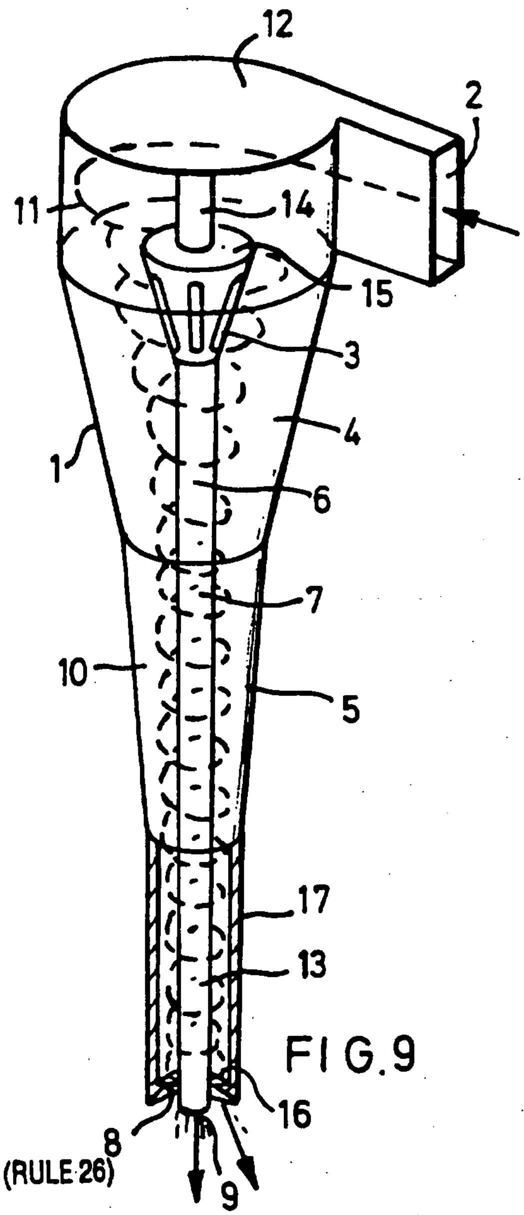


FIG.9

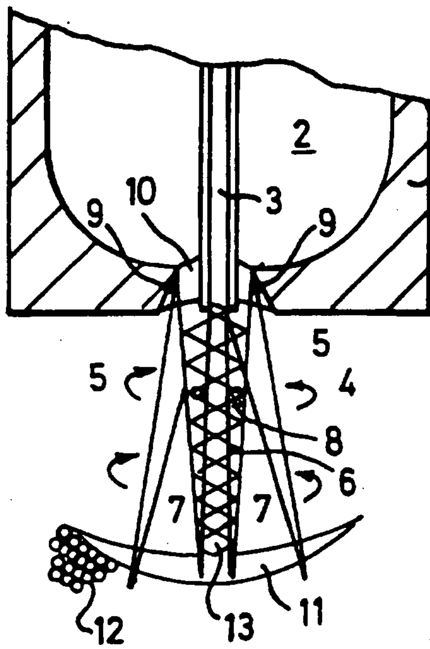


FIG. 10

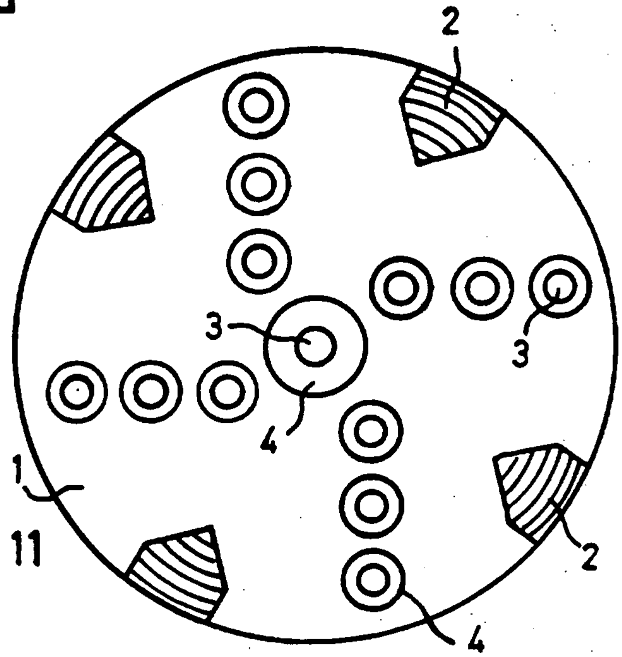


FIG. 11

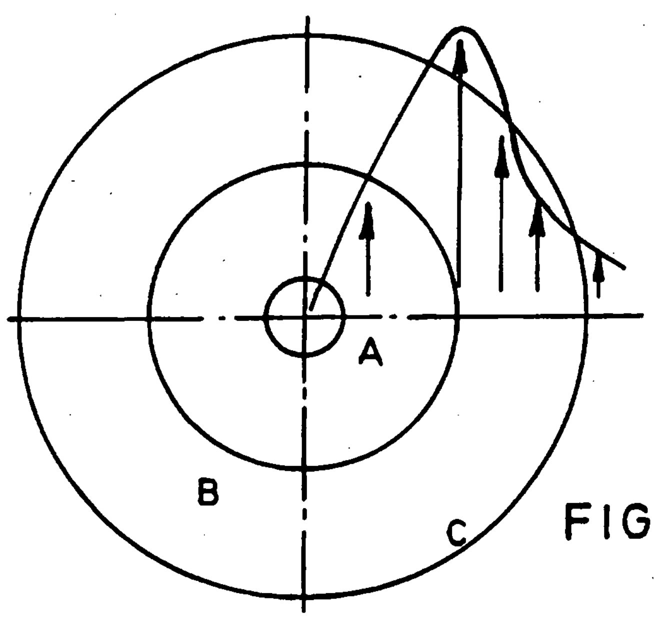


FIG. 12

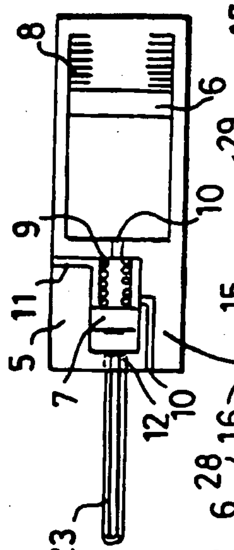


FIG.13

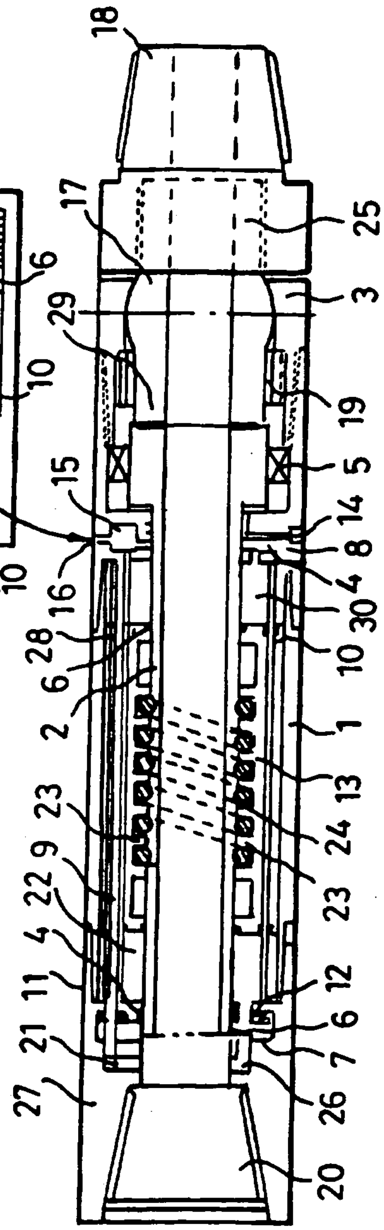
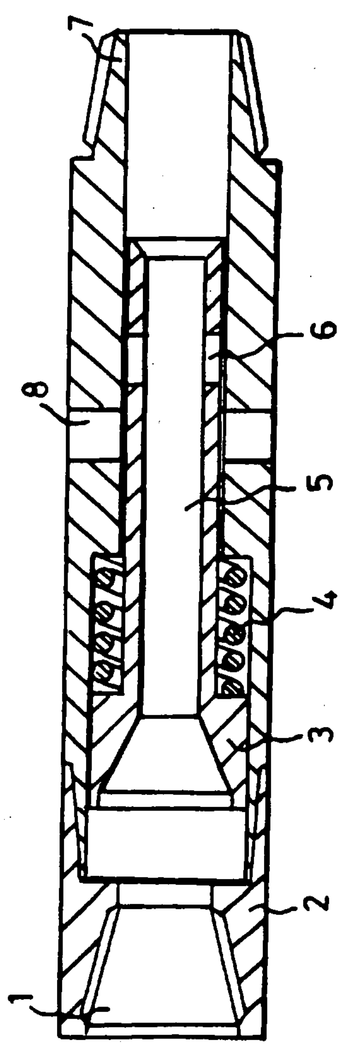


FIG.14

FIG.15



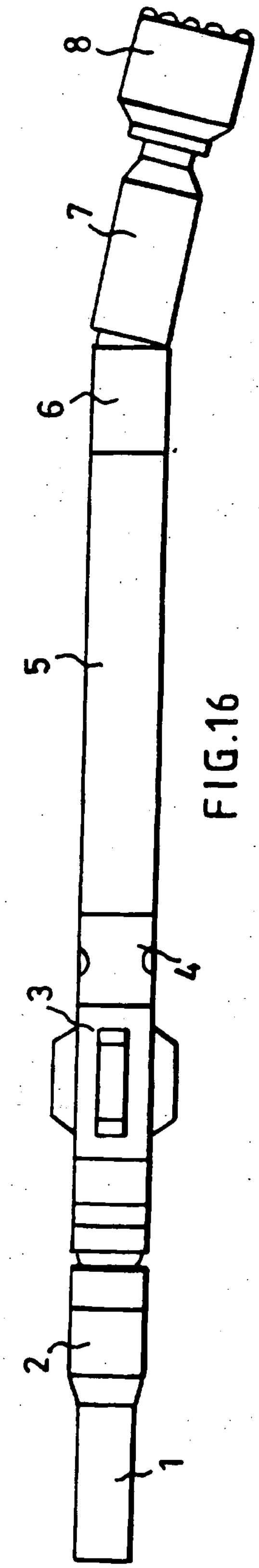
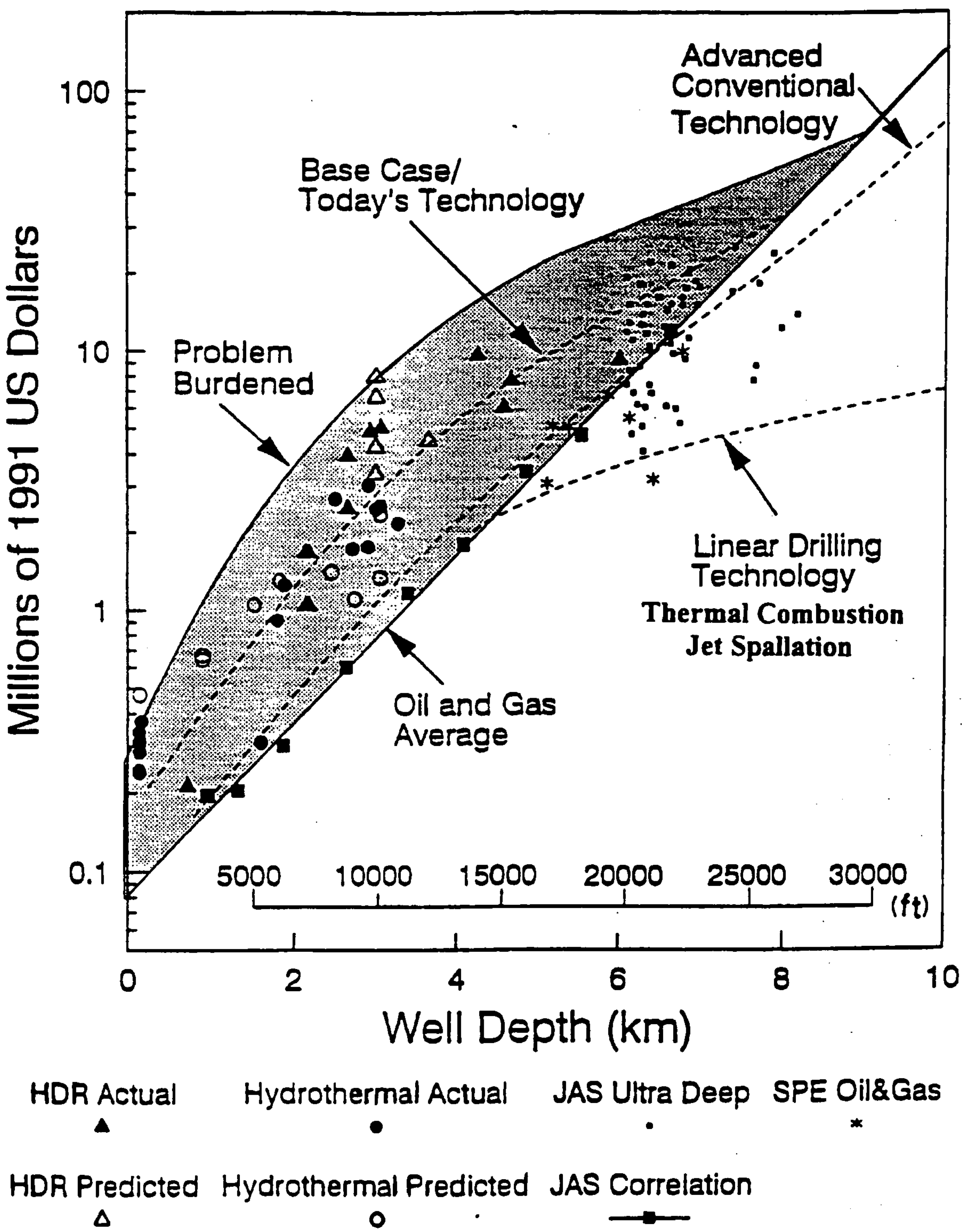


FIG.16

FIG.17

Drilling Costs for Completed Wells



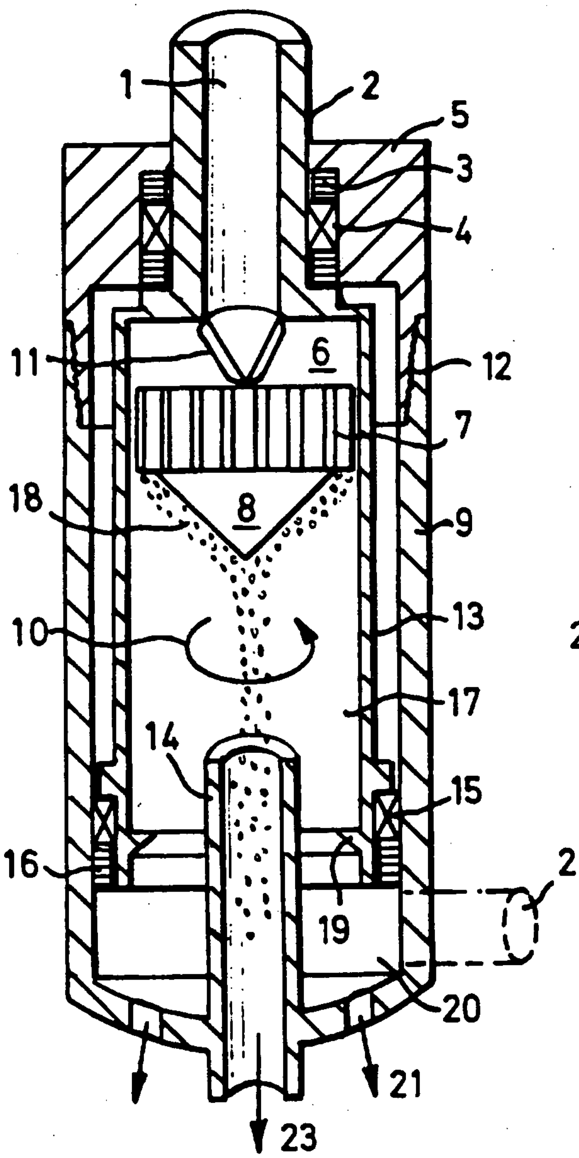


FIG.18

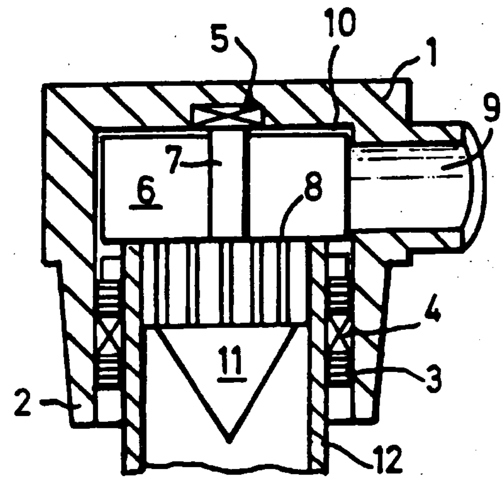


FIG.19

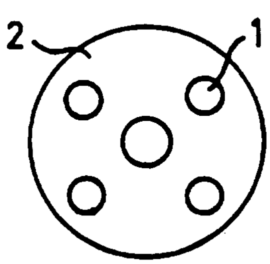


FIG.21

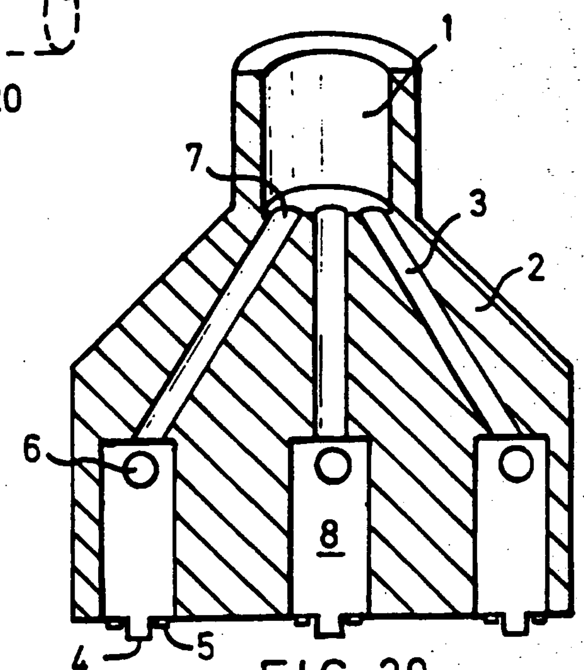


FIG.20

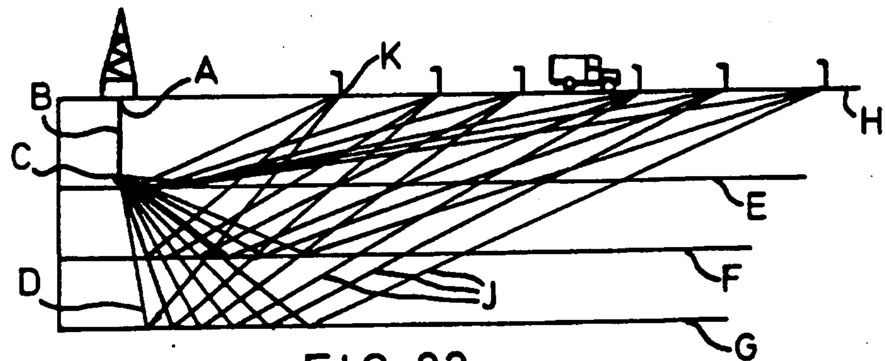


FIG. 22

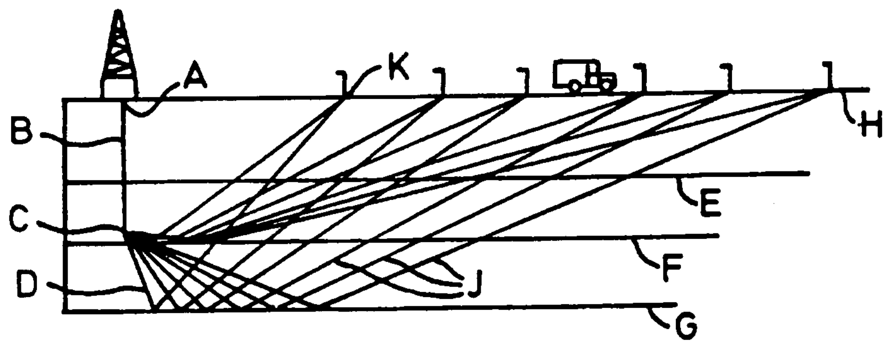


FIG. 23

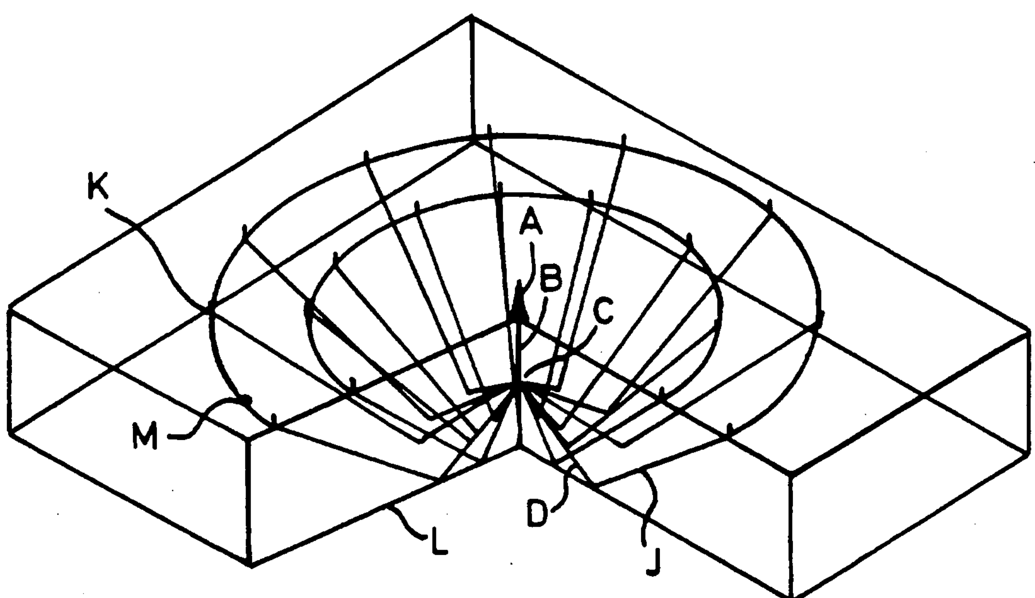


FIG. 24

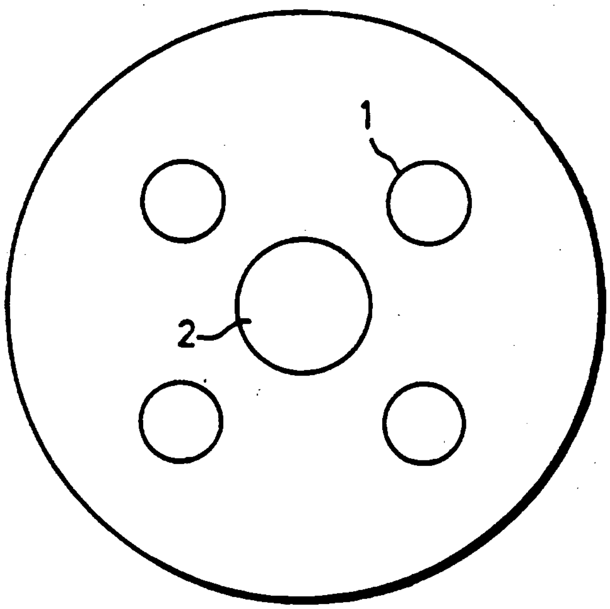


FIG. 25

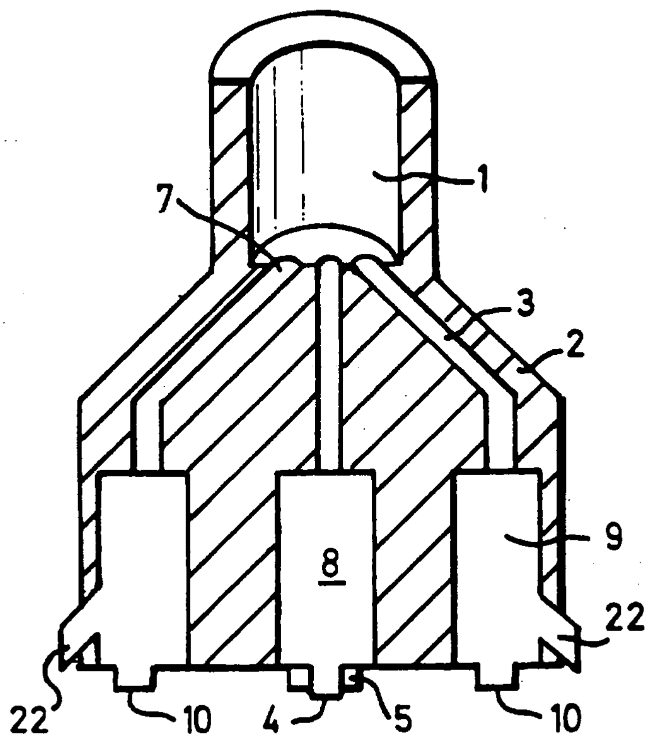


FIG. 26

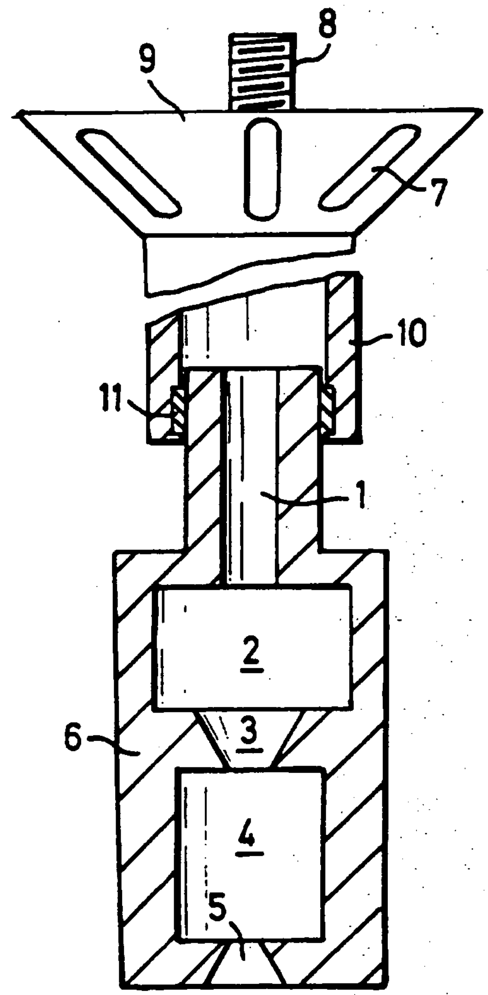


FIG. 27

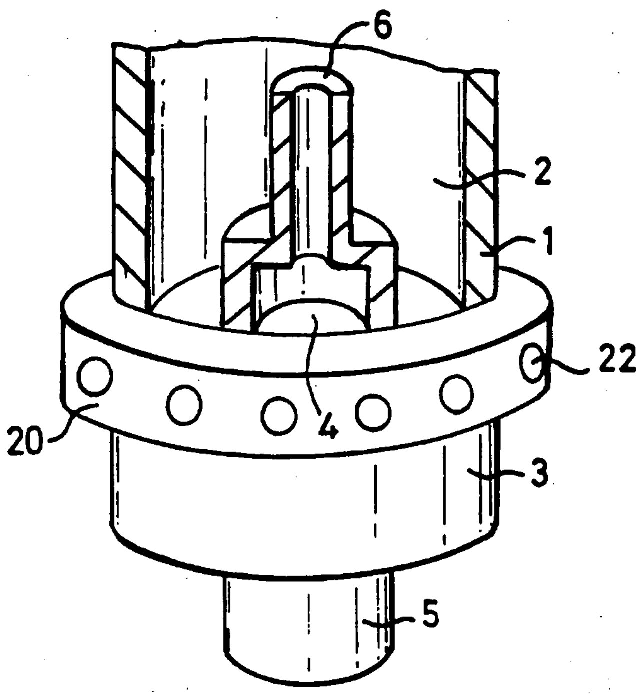


FIG.28

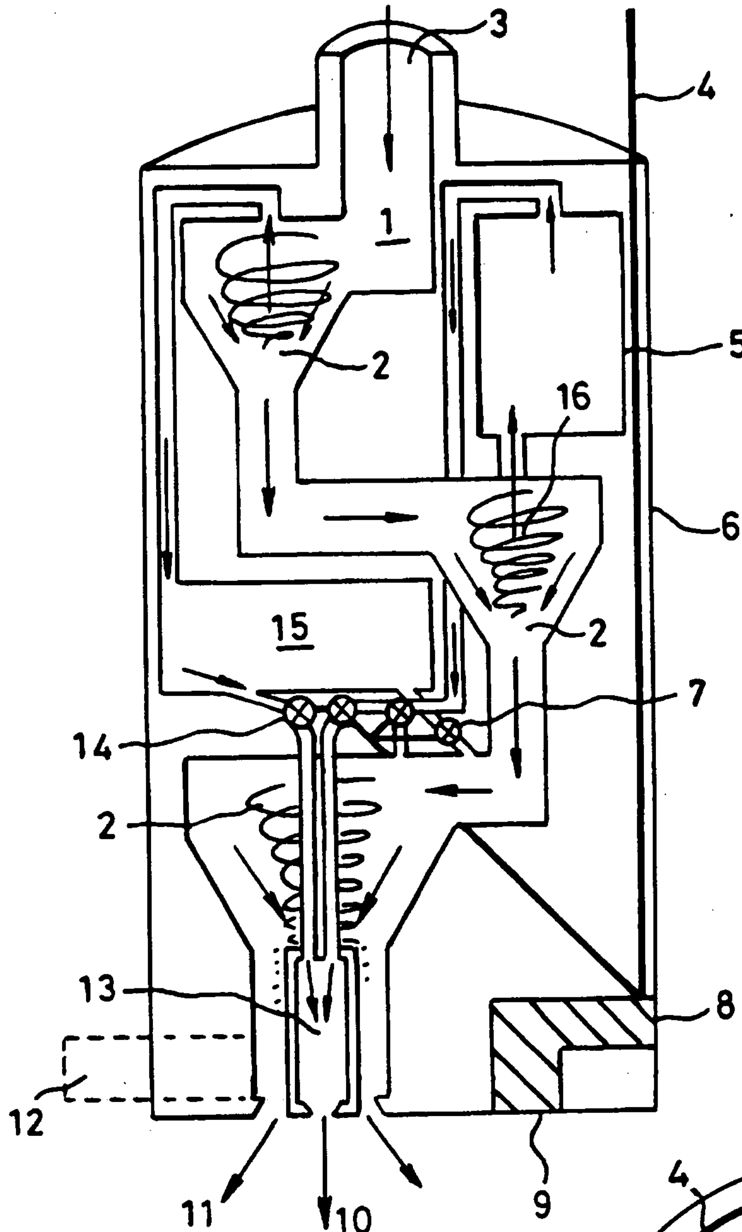


FIG. 30

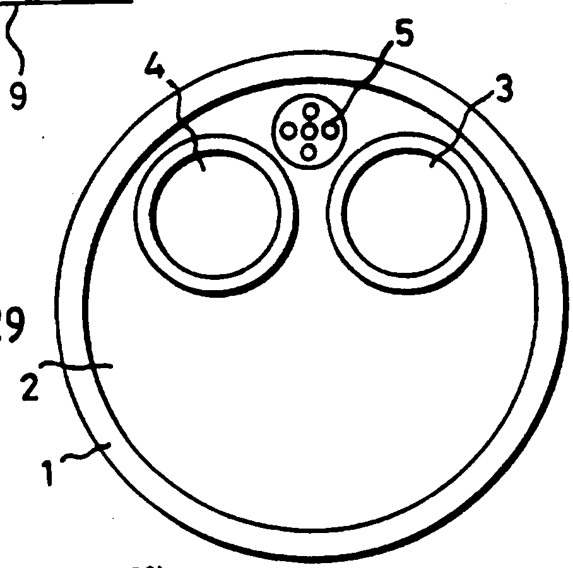


FIG.29

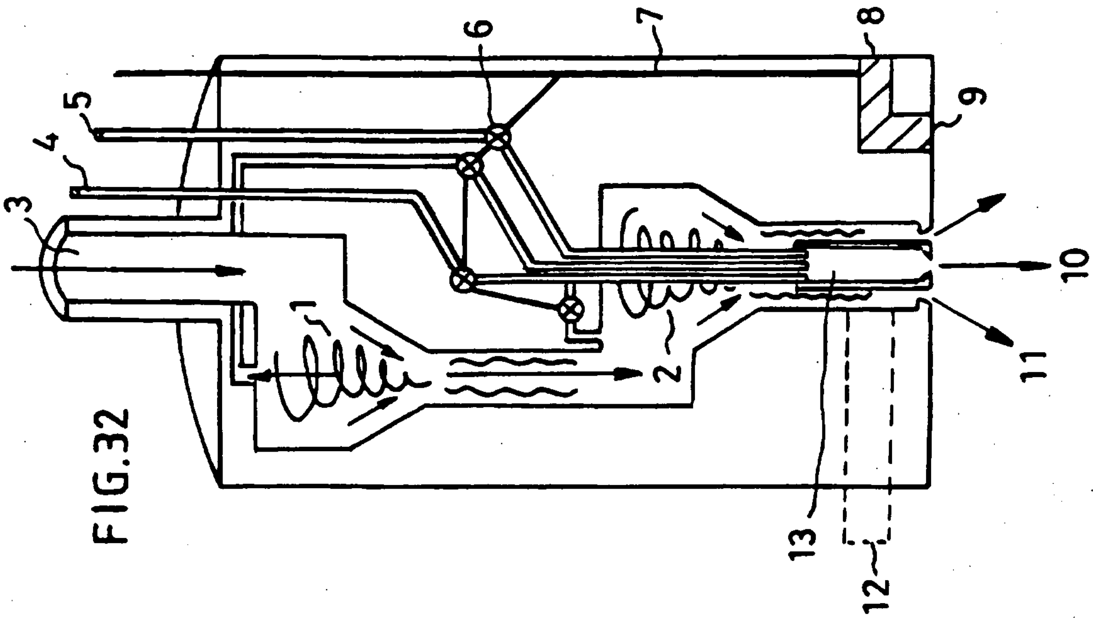


FIG.32

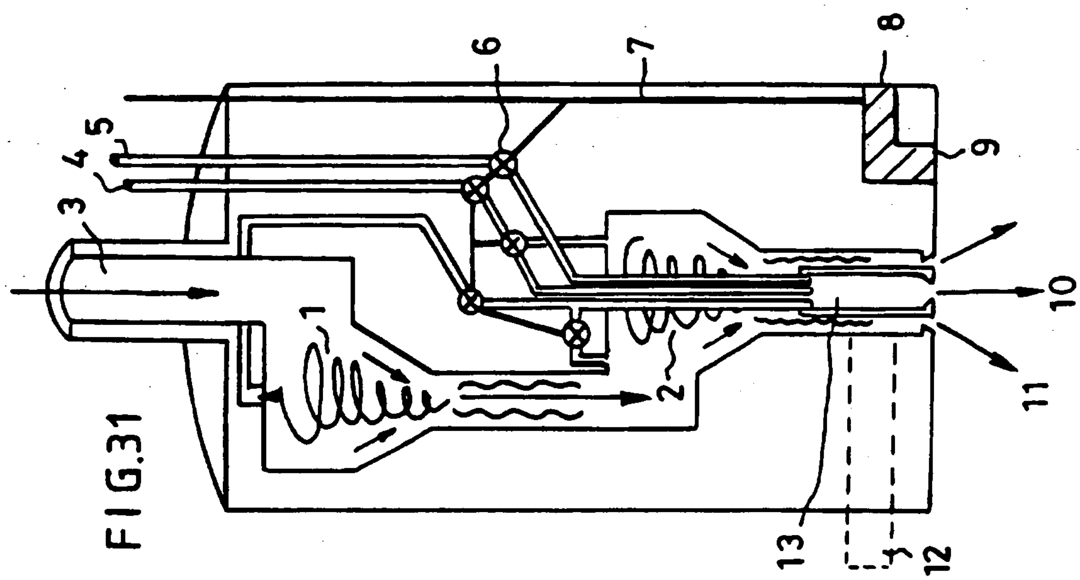


FIG.31

FIG.35

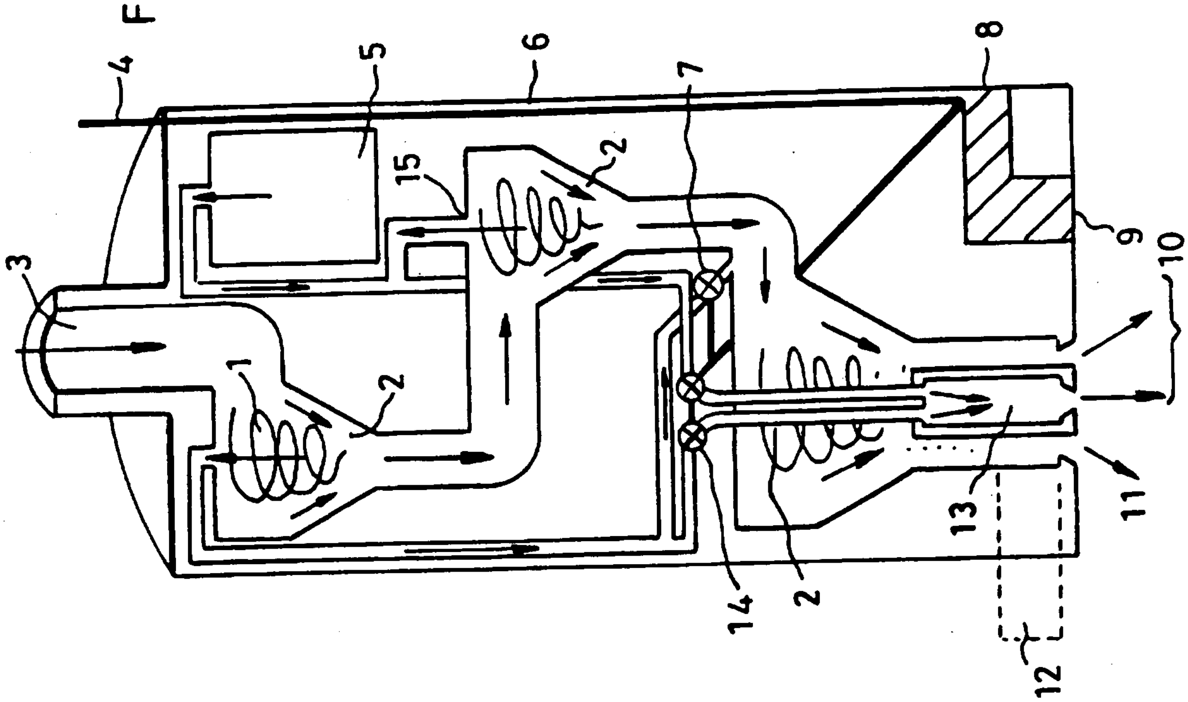
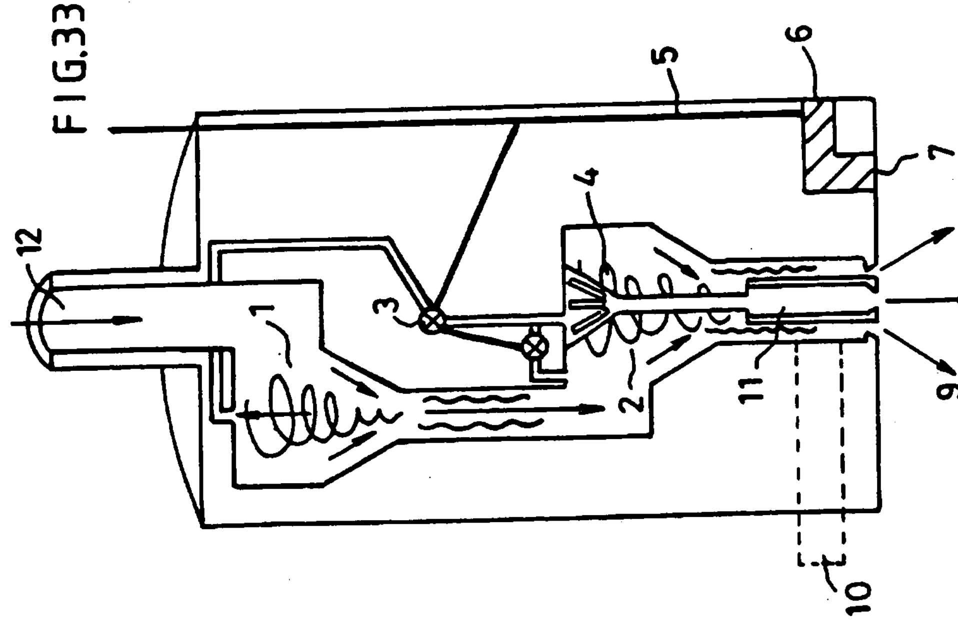


FIG.33



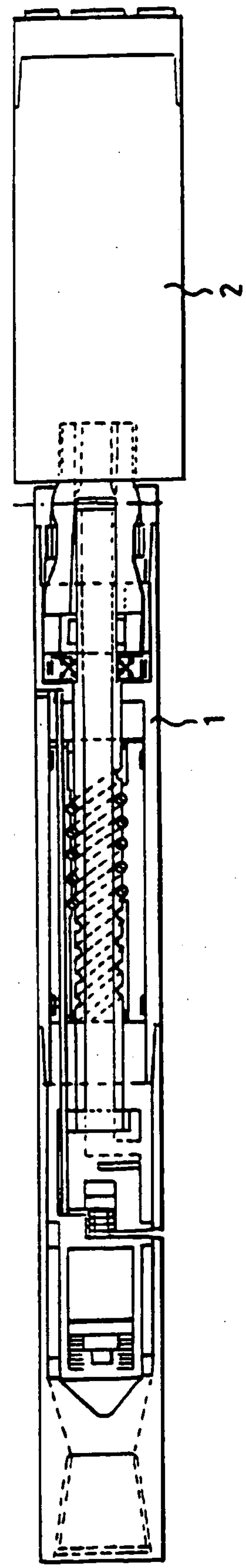
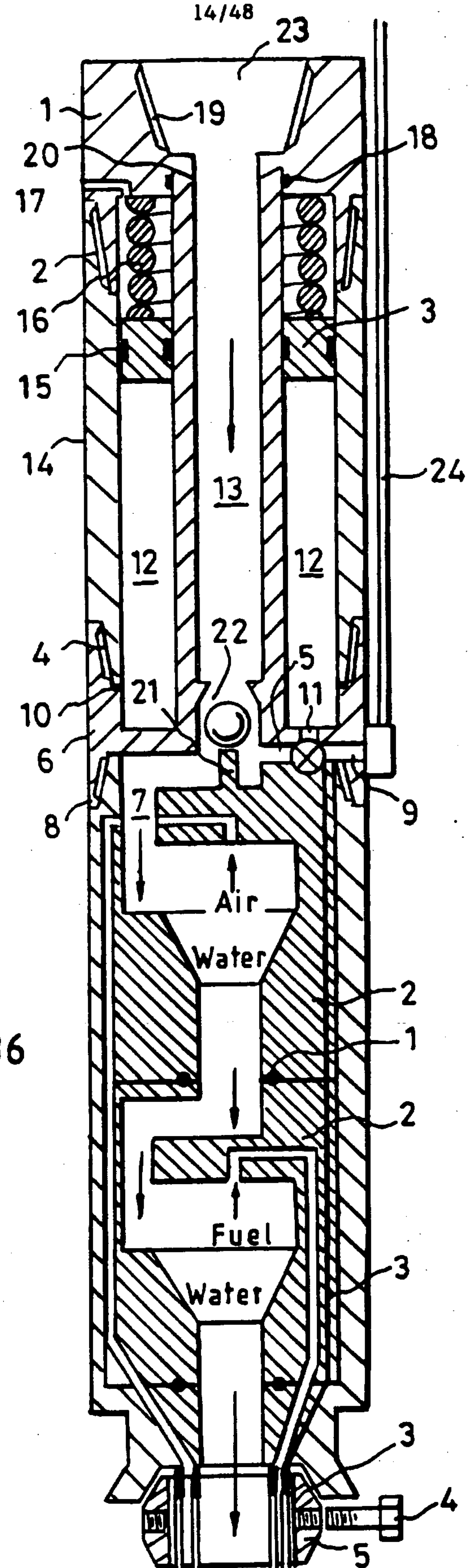


FIG.34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Air
Water
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Fuel
Water
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FIG.37

FIG.36

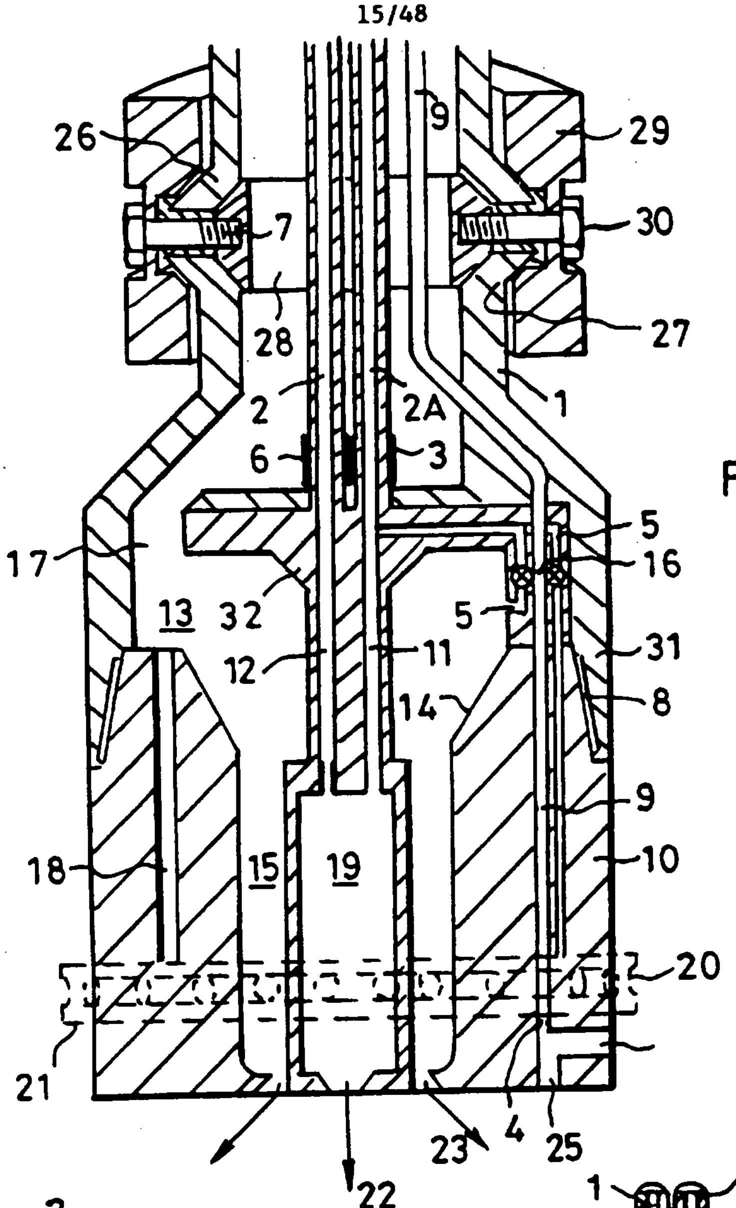


FIG.38

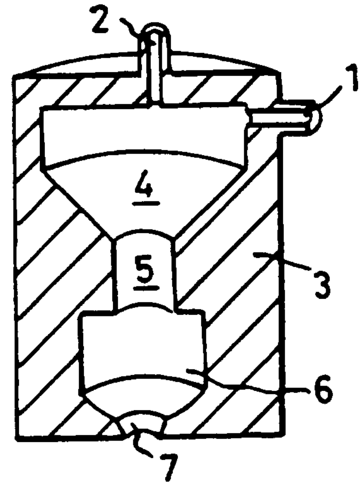


FIG.39

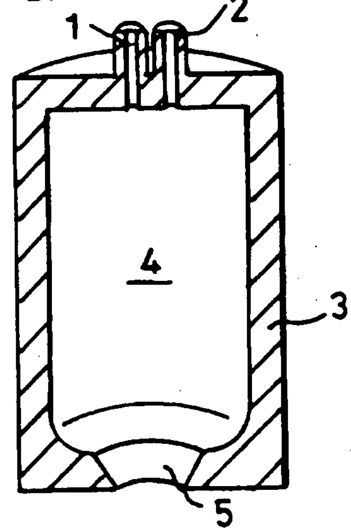
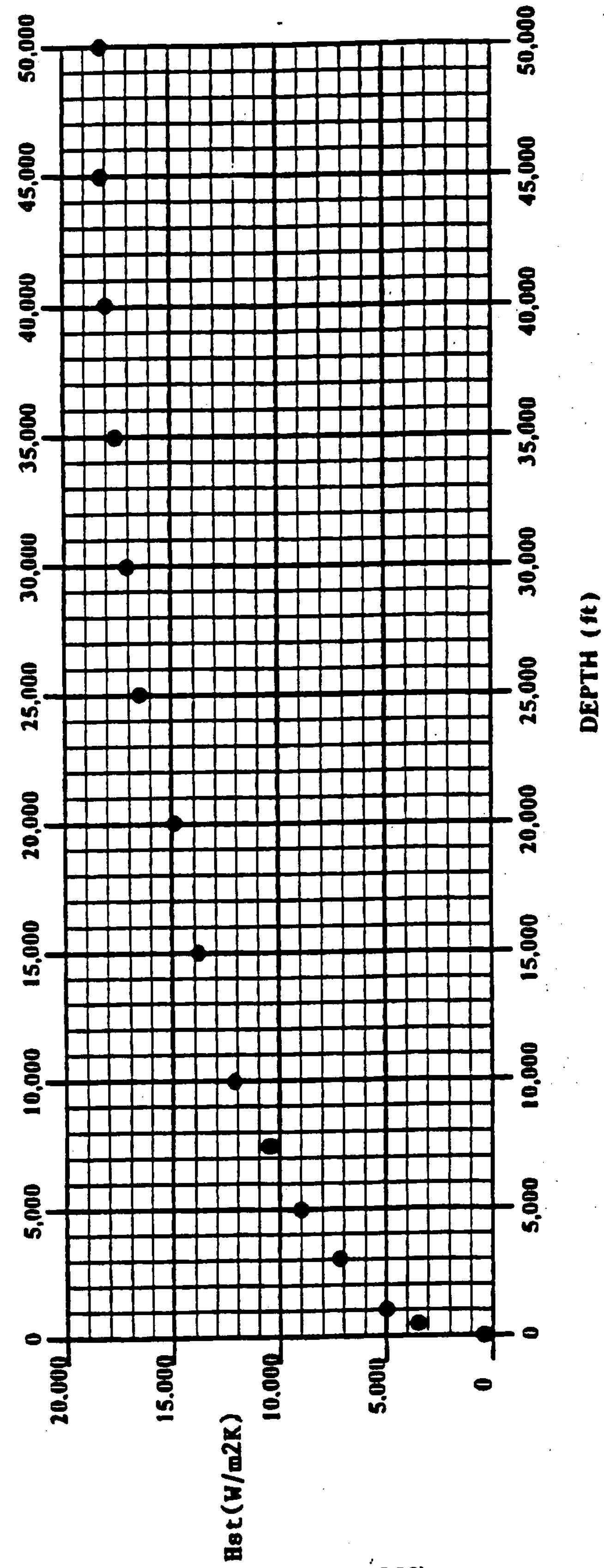


FIG.40

FIG. 41

SUBMERGED COMBUSTION FLAME JETS

NORMAL HYDSROSTATIC + CHAMBER PRESSURE @ 500 PSI = 1,800 Deg. C TEMPERATURE



HEAT TRANSFER COEFFICIENTS WITH SUBMERGED COMBUSTION FLAME JETS IN PRESSURIZED WATER IN THE WELL BORE (FULL SCALE AT DEPTHS)

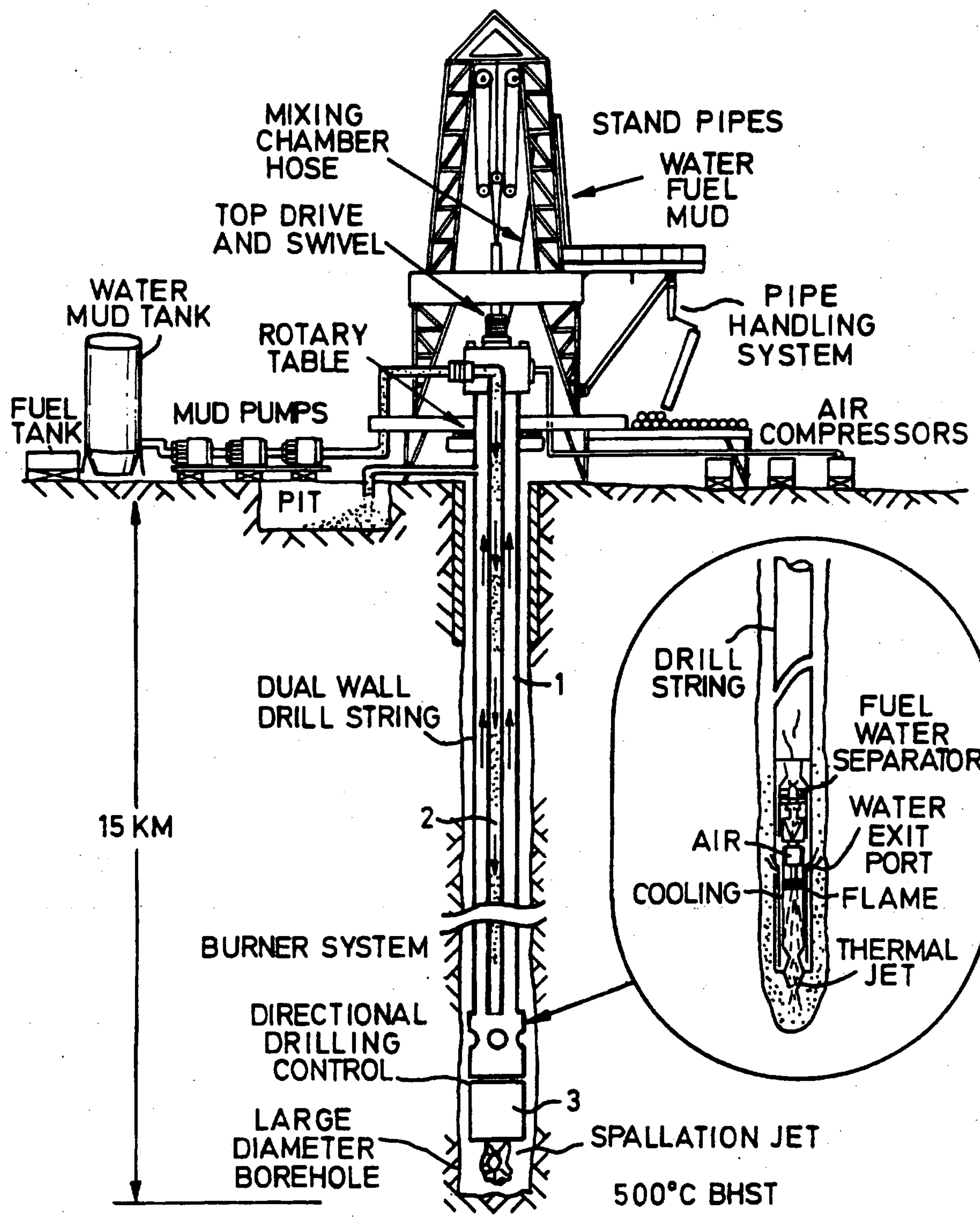

MIXING CHAMBER HOSE
STAND PIPES
WATER FUEL MUD
TOP DRIVE AND SWIVEL
WATER MUD TANK
ROTARY TABLE
PIPE HANDLING SYSTEM
FUEL TANK
MUD PUMPS
AIR COMPRESSORS
PIT
DRILL STRING
FUEL WATER SEPARATOR
DUAL WALL DRILL STRING
1
WATER EXIT PORT
AIR
2
15 KM
COOLING
FLAME
BURNER SYSTEM
THERMAL JET
DIRECTIONAL DRILLING CONTROL
3
LARGE DIAMETER BOREHOLE
SPALLATION JET
500°C BHST

FIG. 42

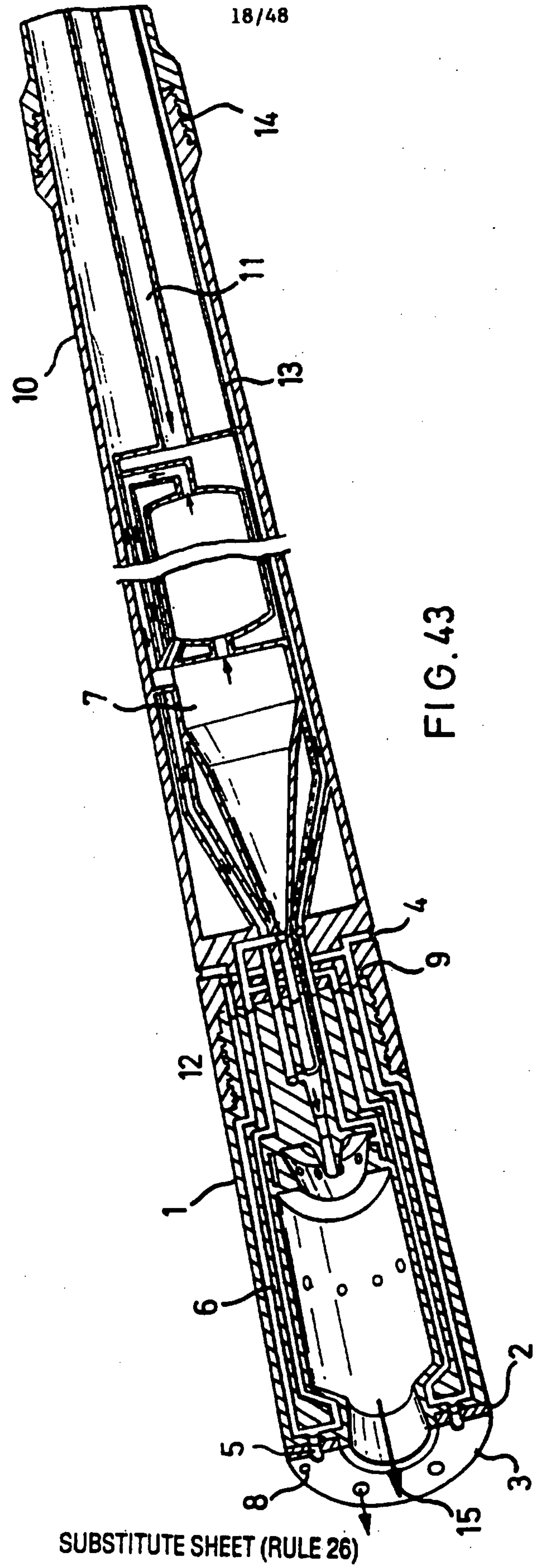


FIG.43

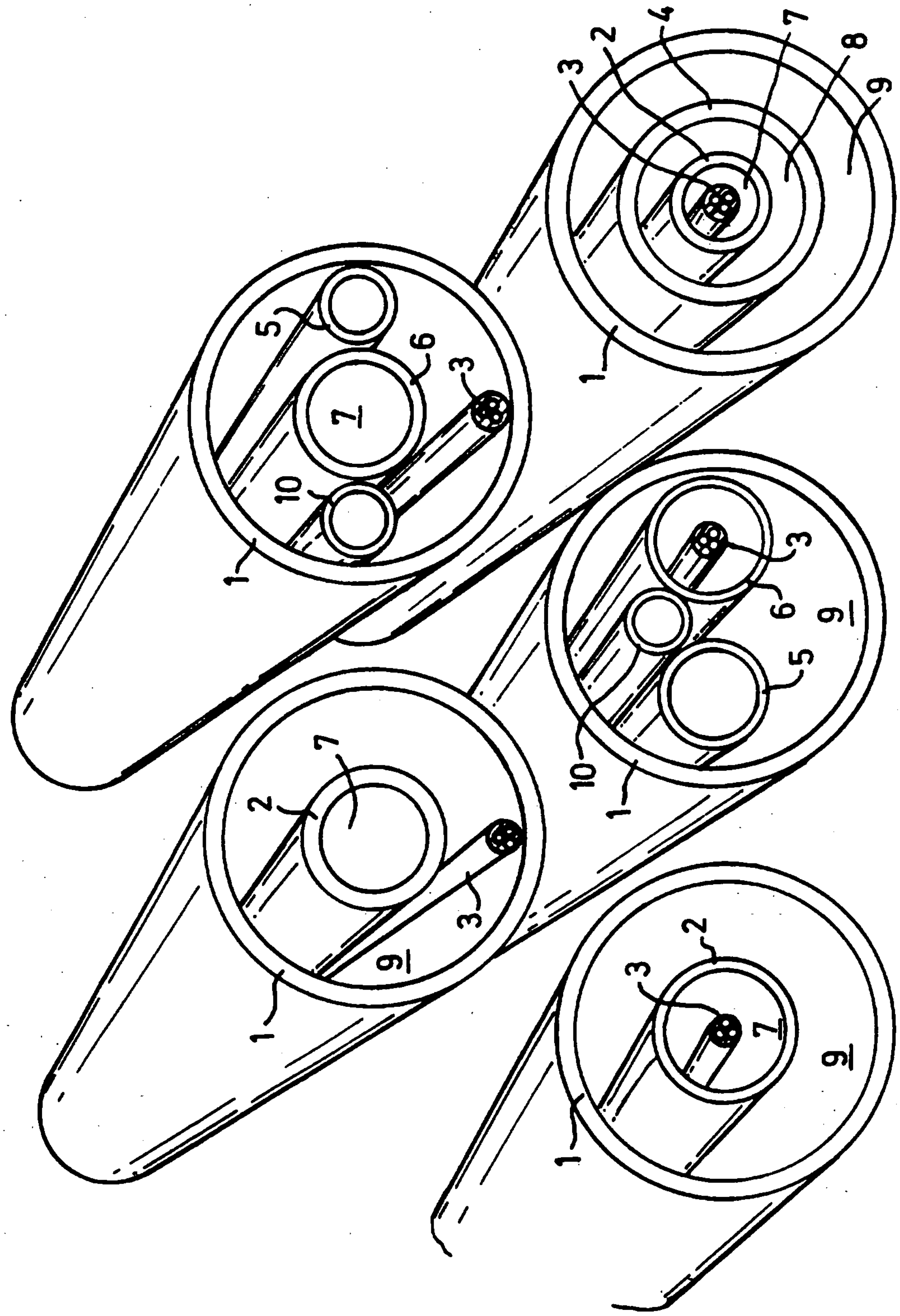


FIG. 44

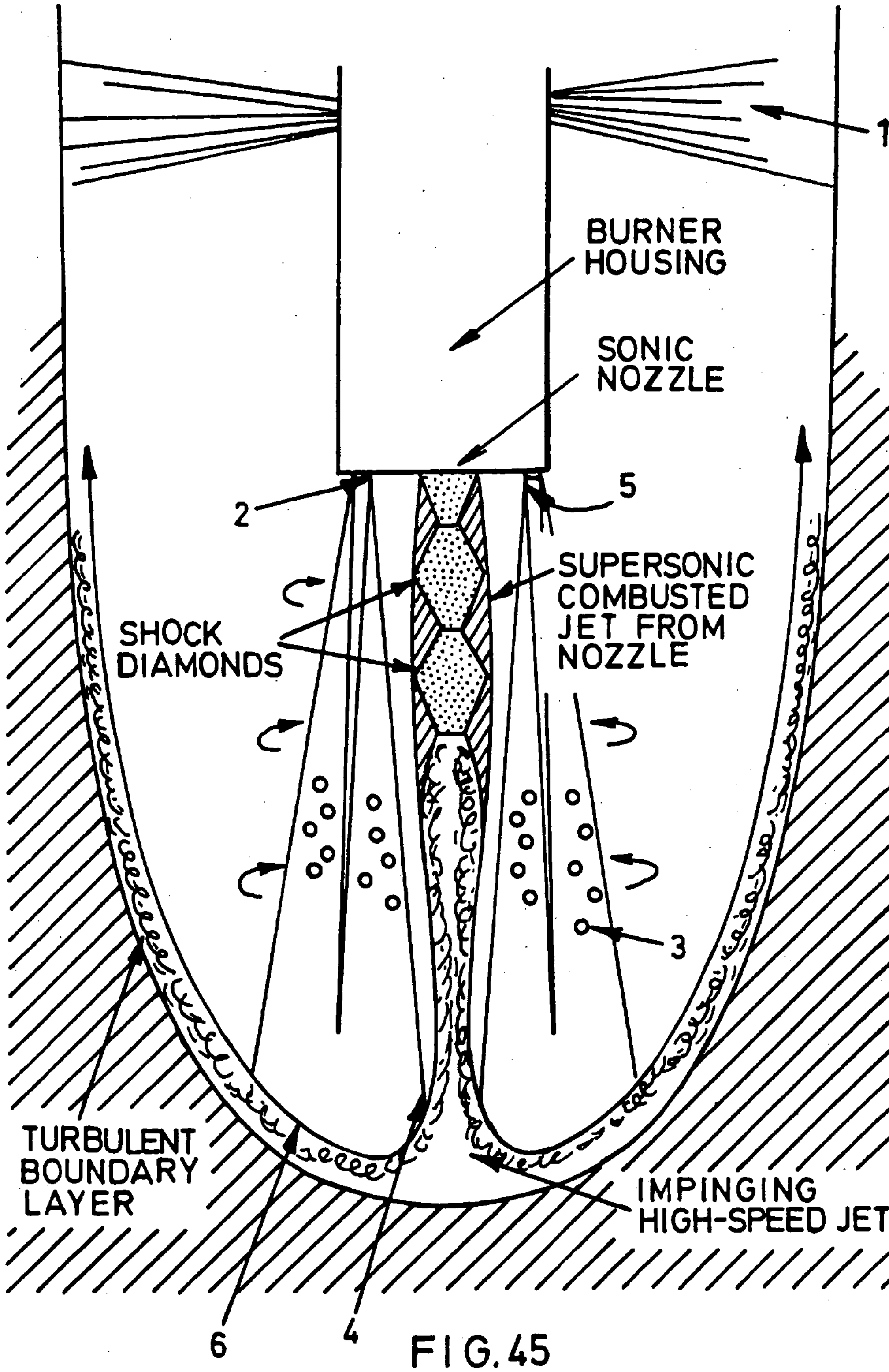

1
BURNER HOUSING
SONIC NOZZLE
2
5
SUPERSONIC COMBUSTED JET FROM NOZZLE
SHOCK DIAMONDS
3
TURBULENT BOUNDARY LAYER
IMPINGING HIGH-SPEED JET
6
4

FIG. 45

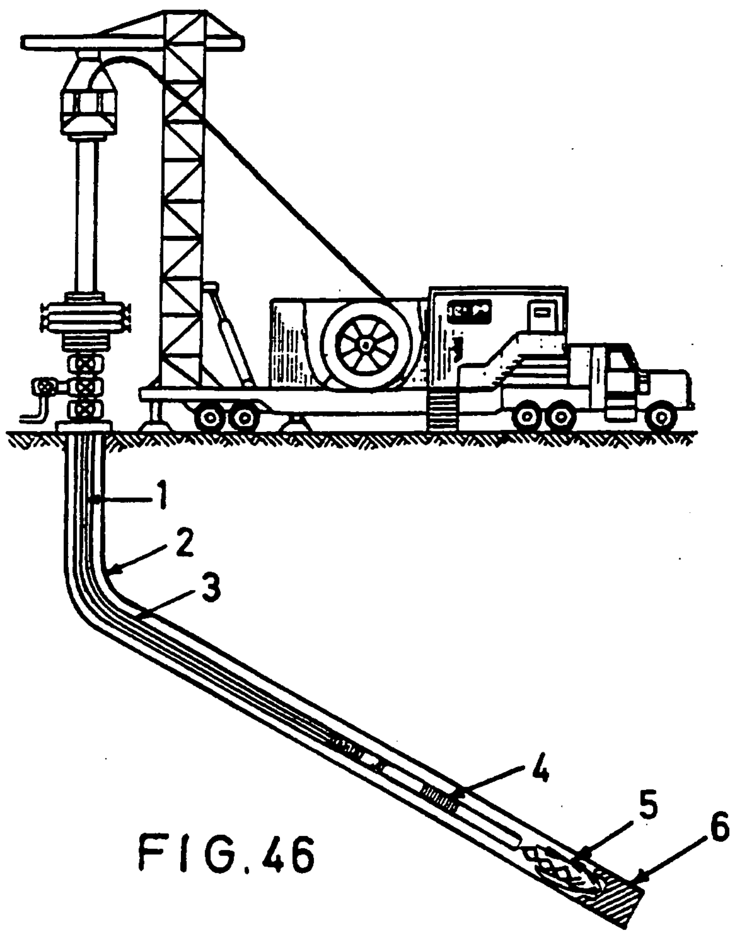


FIG. 46

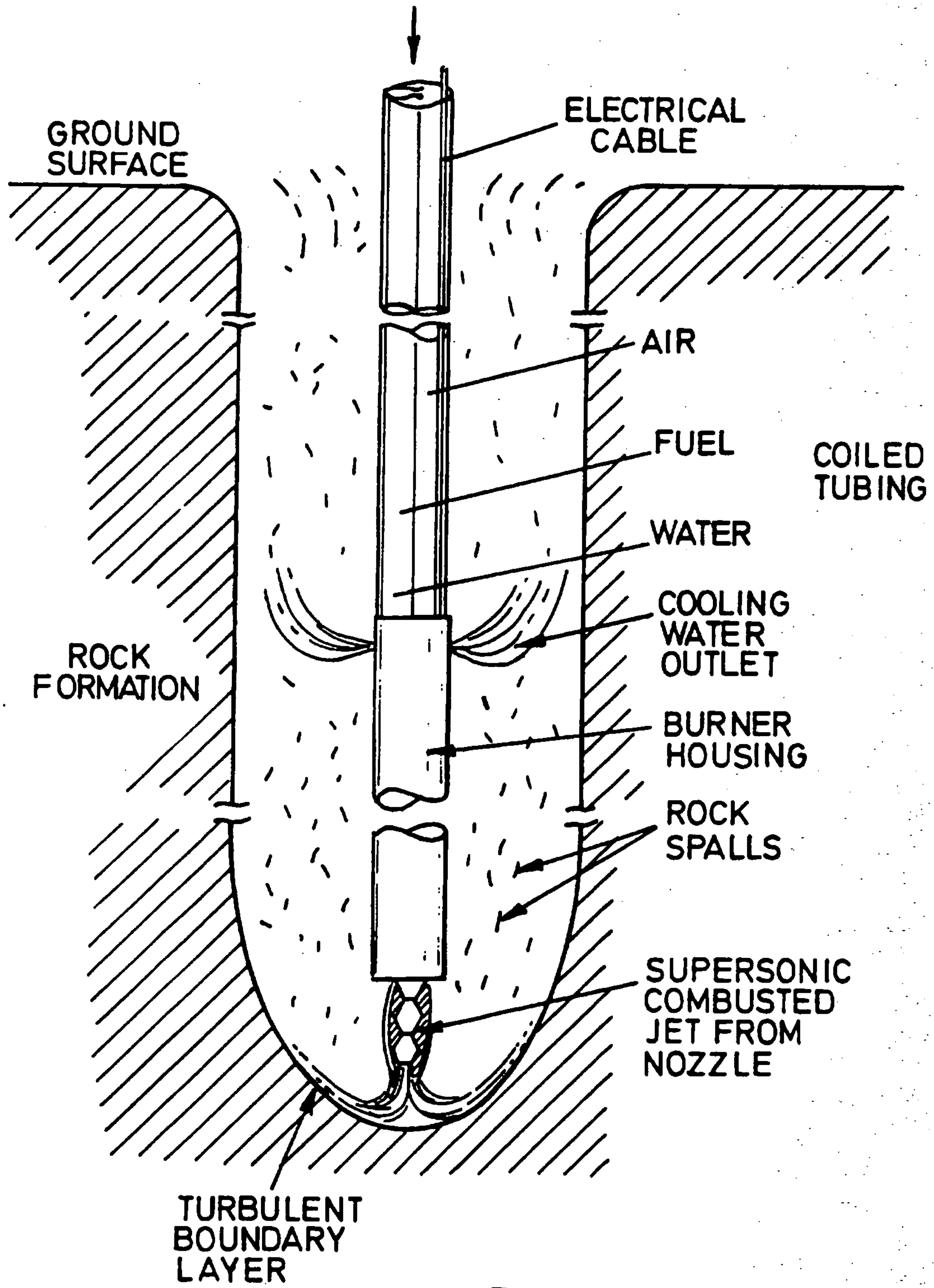

ELECTRICAL CABLE
GROUND SURFACE
AIR
FUEL
COILED TUBING
WATER
COOLING WATER OUTLET
ROCK FORMATION
BURNER HOUSING
ROCK SPALLS
SUPERSONIC COMBUSTED JET FROM NOZZLE
TURBULENT BOUNDARY LAYER

FIG. 47

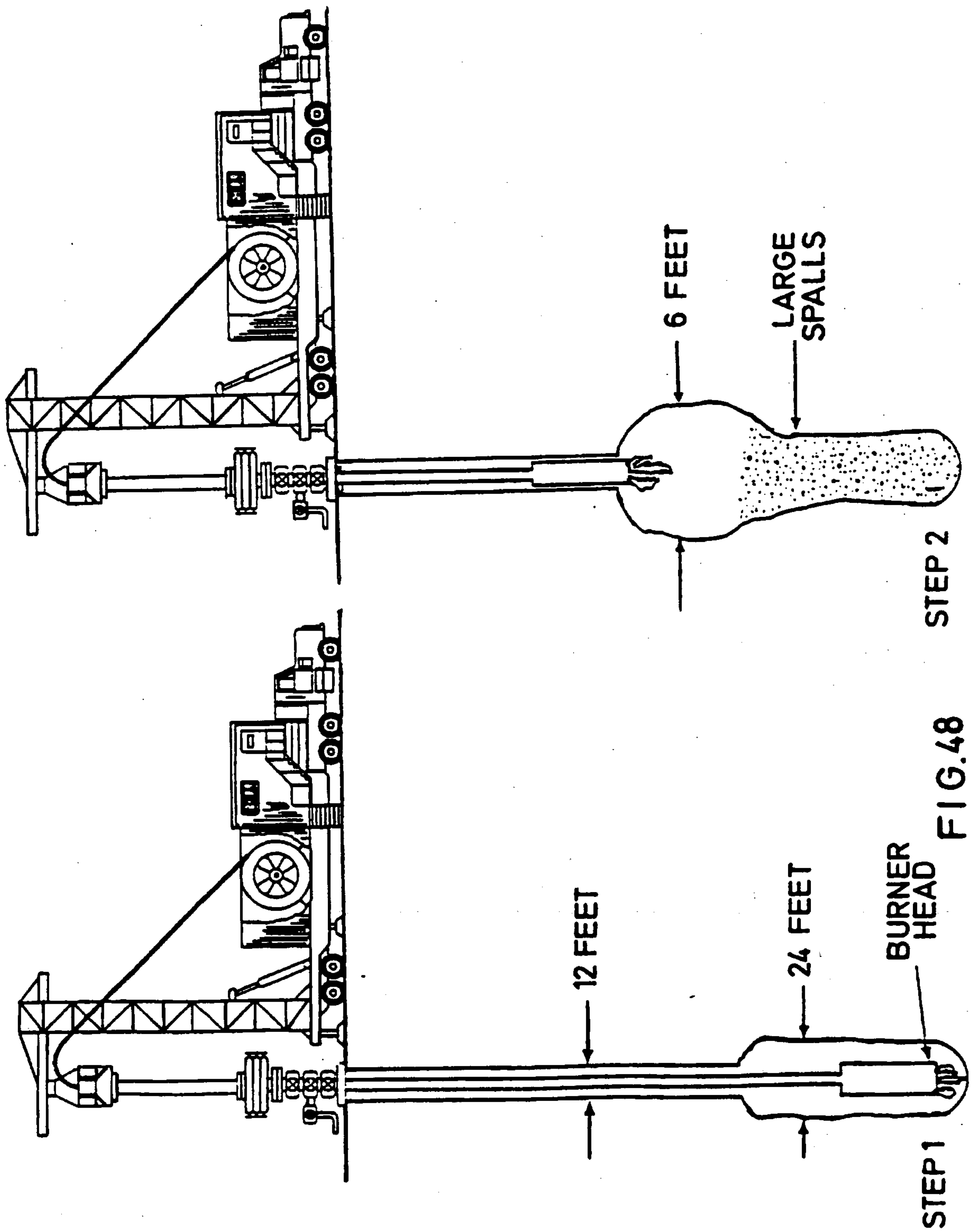


FIG.48

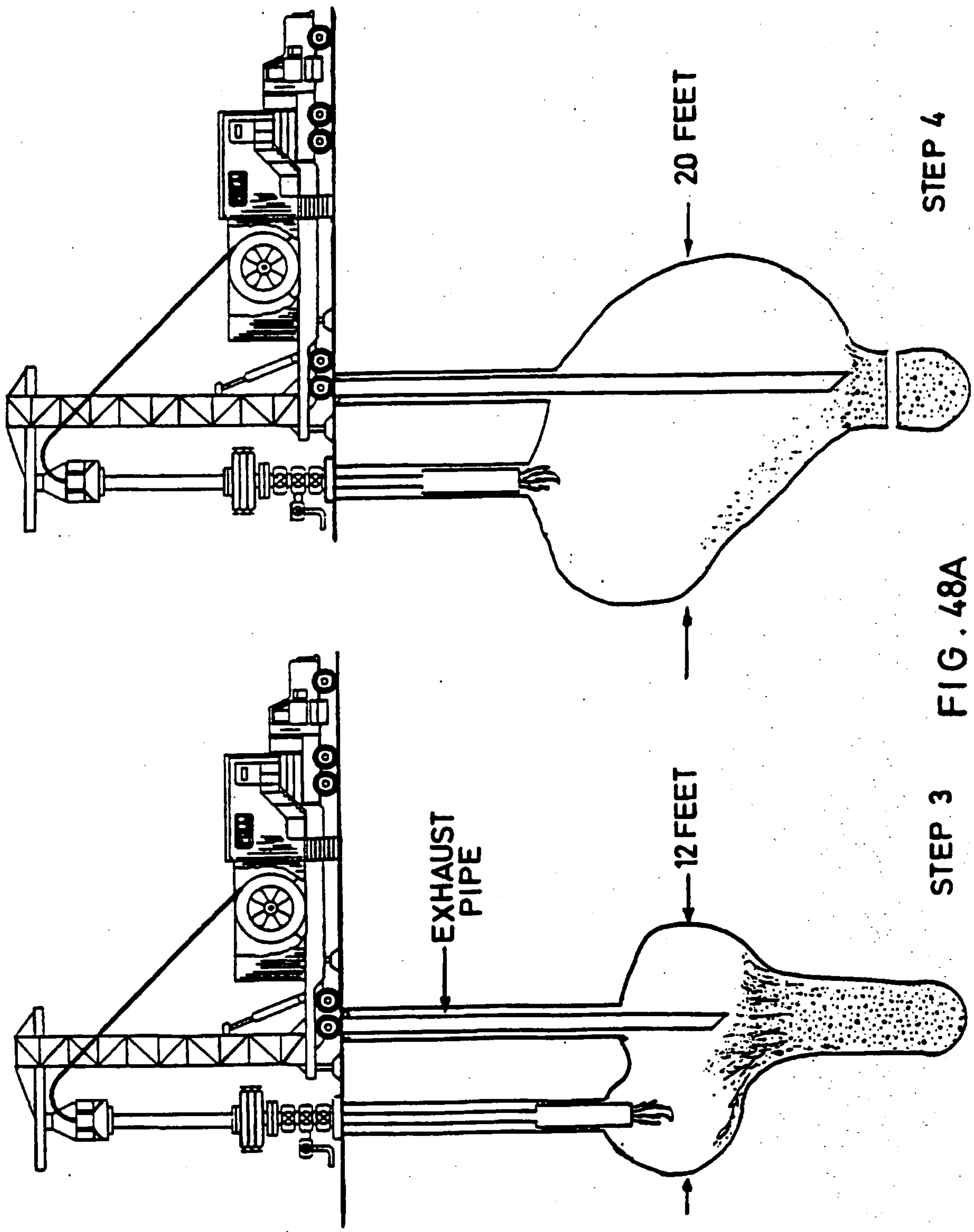


FIG. 48A

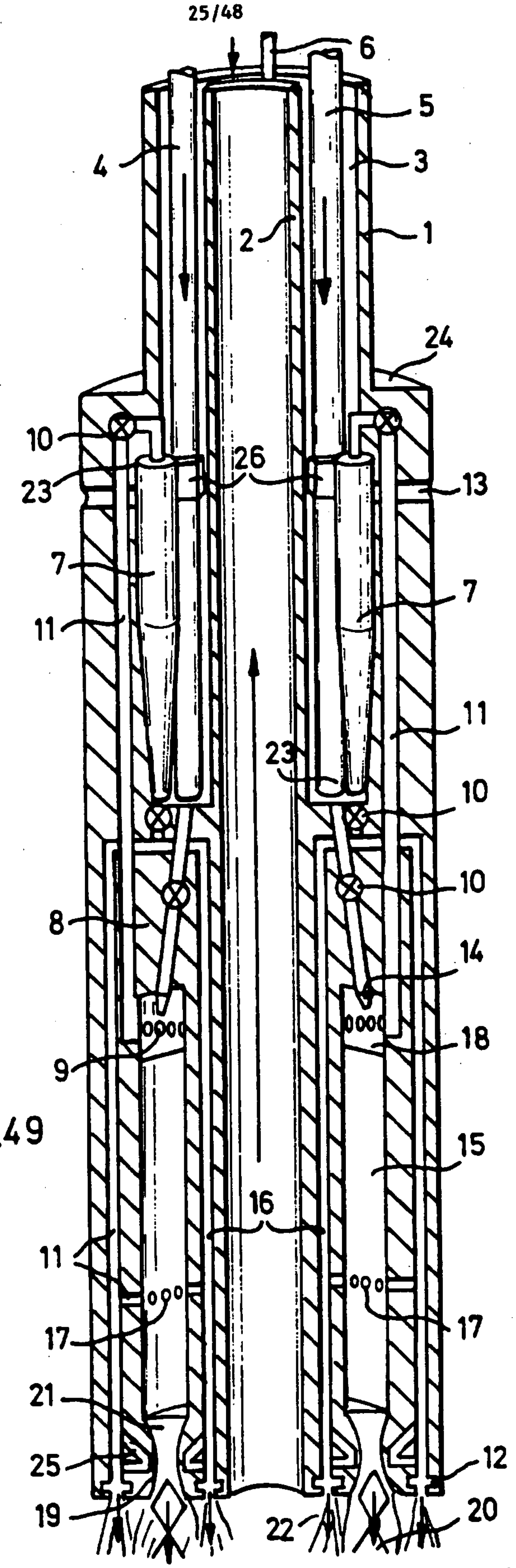


FIG.49

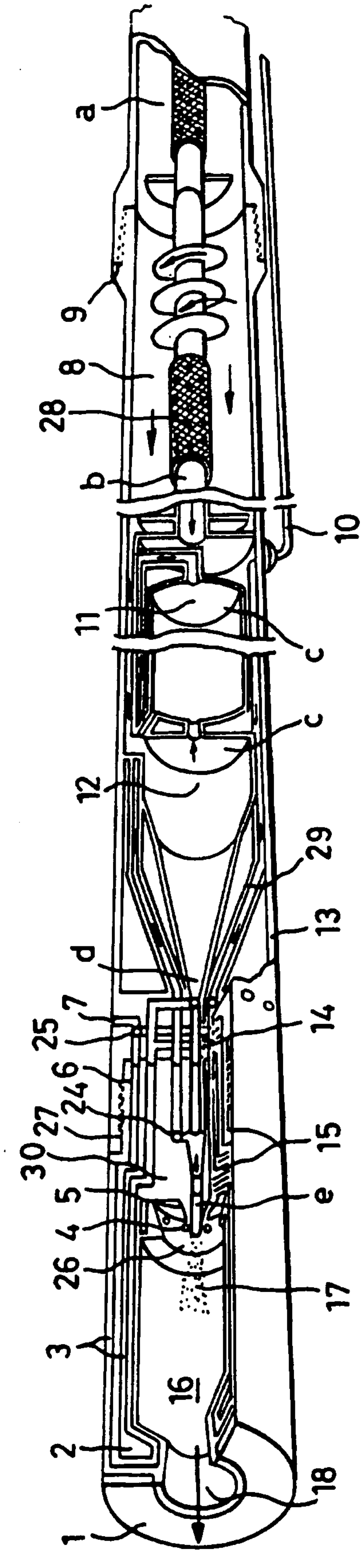


FIG.50

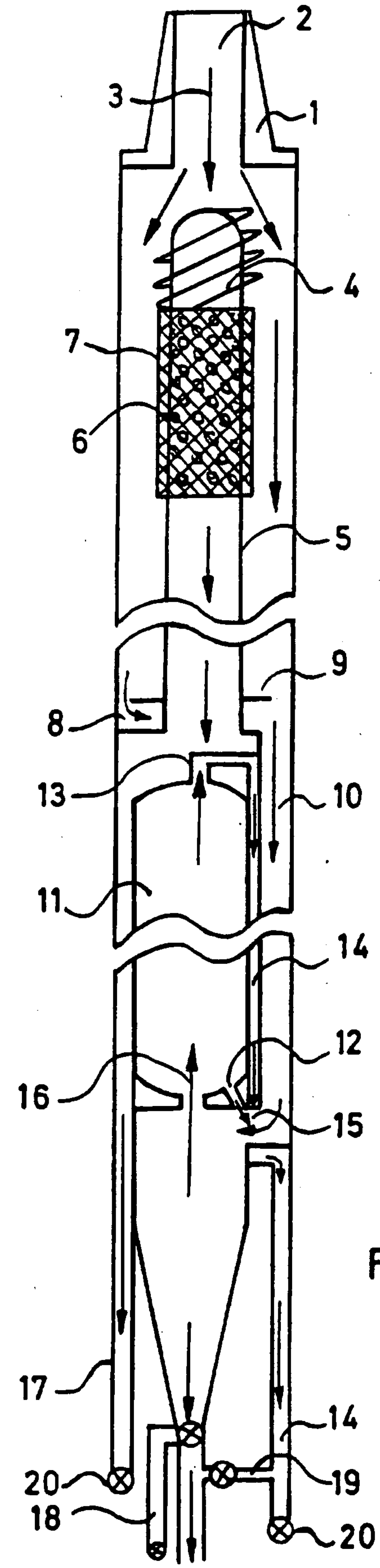


FIG.51

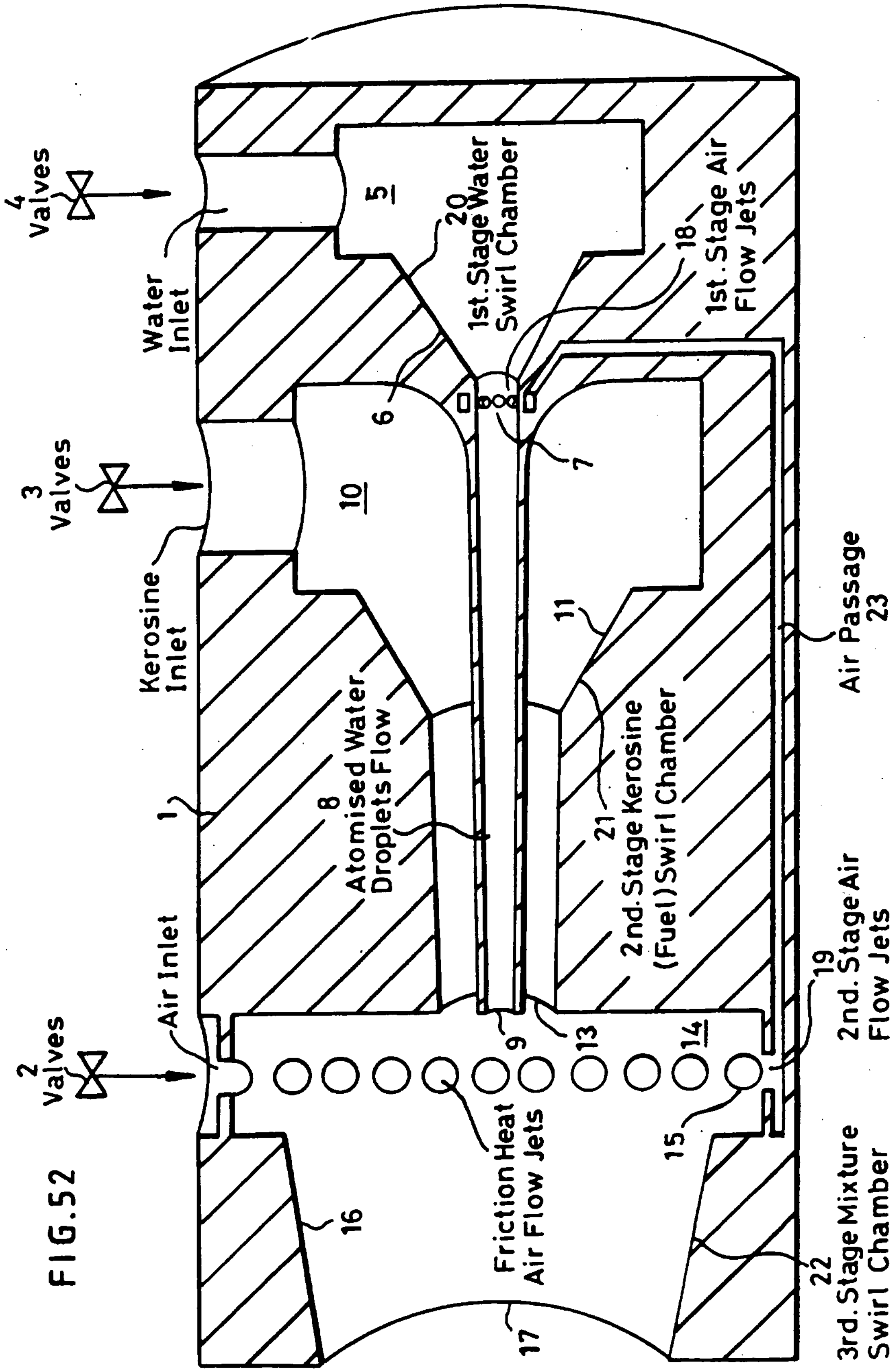

4 Valves
Water Inlet
3 Valves
Kerosine Inlet
1
Air Inlet
2 Valves
5
20
1st. Stage Water Swirl Chamber
18
1st. Stage Air Flow Jets
6
7
10
11
Air Passage 23
8
Atomised Water Droplets Flow
21
2nd. Stage Kerosine (Fuel) Swirl Chamber
19
2nd. Stage Air Flow Jets
9
13
14
15
Friction Heat Air Flow Jets
16
17
22
3rd. Stage Mixture Swirl Chamber

FIG.52

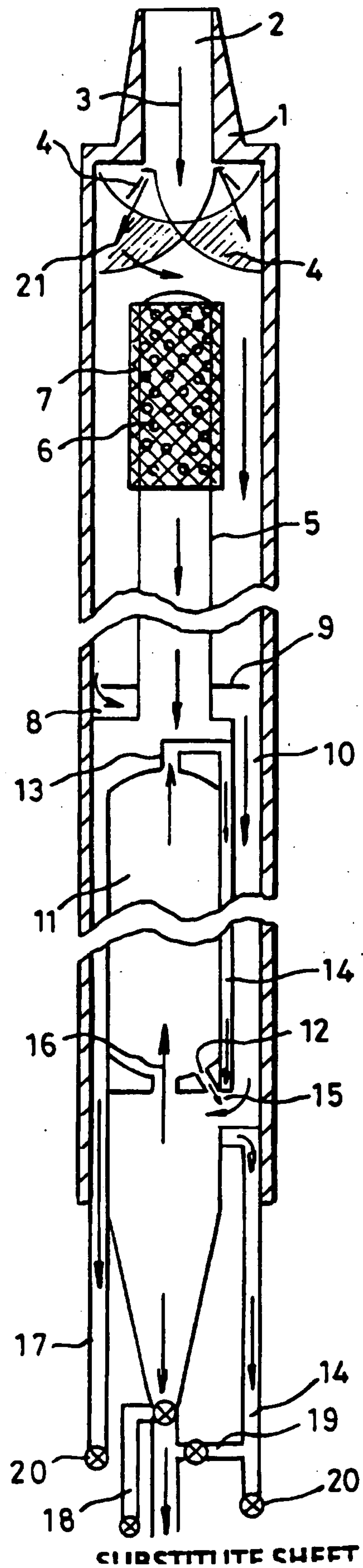


FIG.53

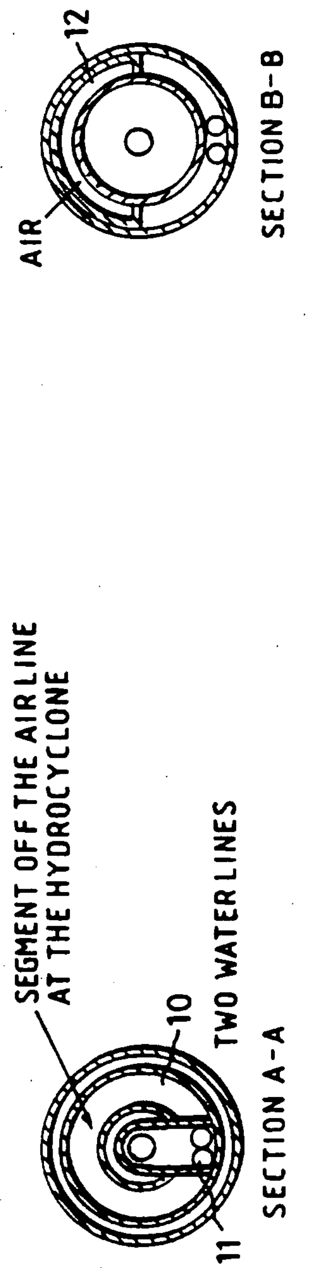
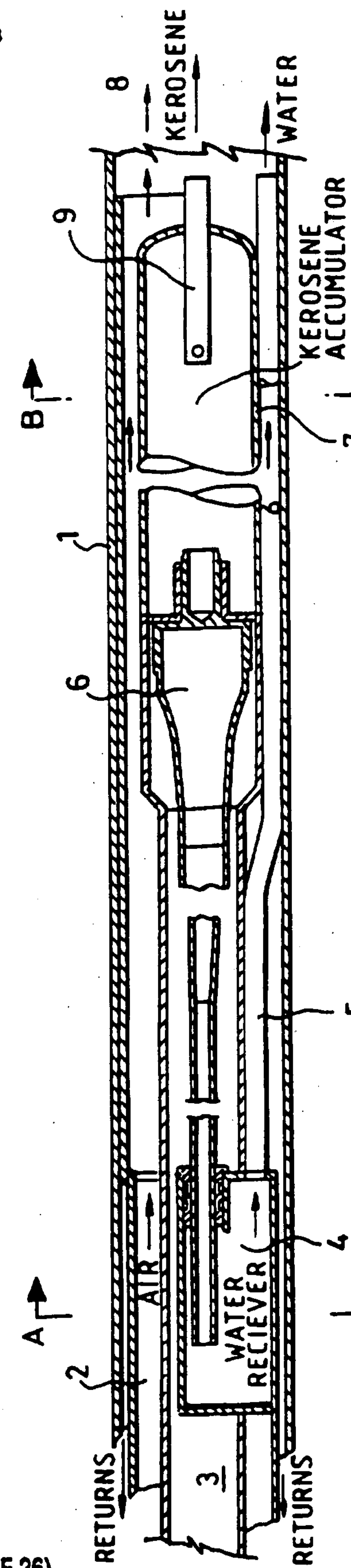

SEGMENT OFF THE AIR LINE AT THE HYDROCYCLONE
10
TWO WATER LINES
11
SECTION A-A
AIR
12
SECTION B-B

FIG.54


8
KEROSENE
WATER
9
KEROSENE ACCUMULATOR
B
B
7
1
6
5
AIR
WATER RECIEVER
4
A
A
2
RETURNS
3
RETURNS

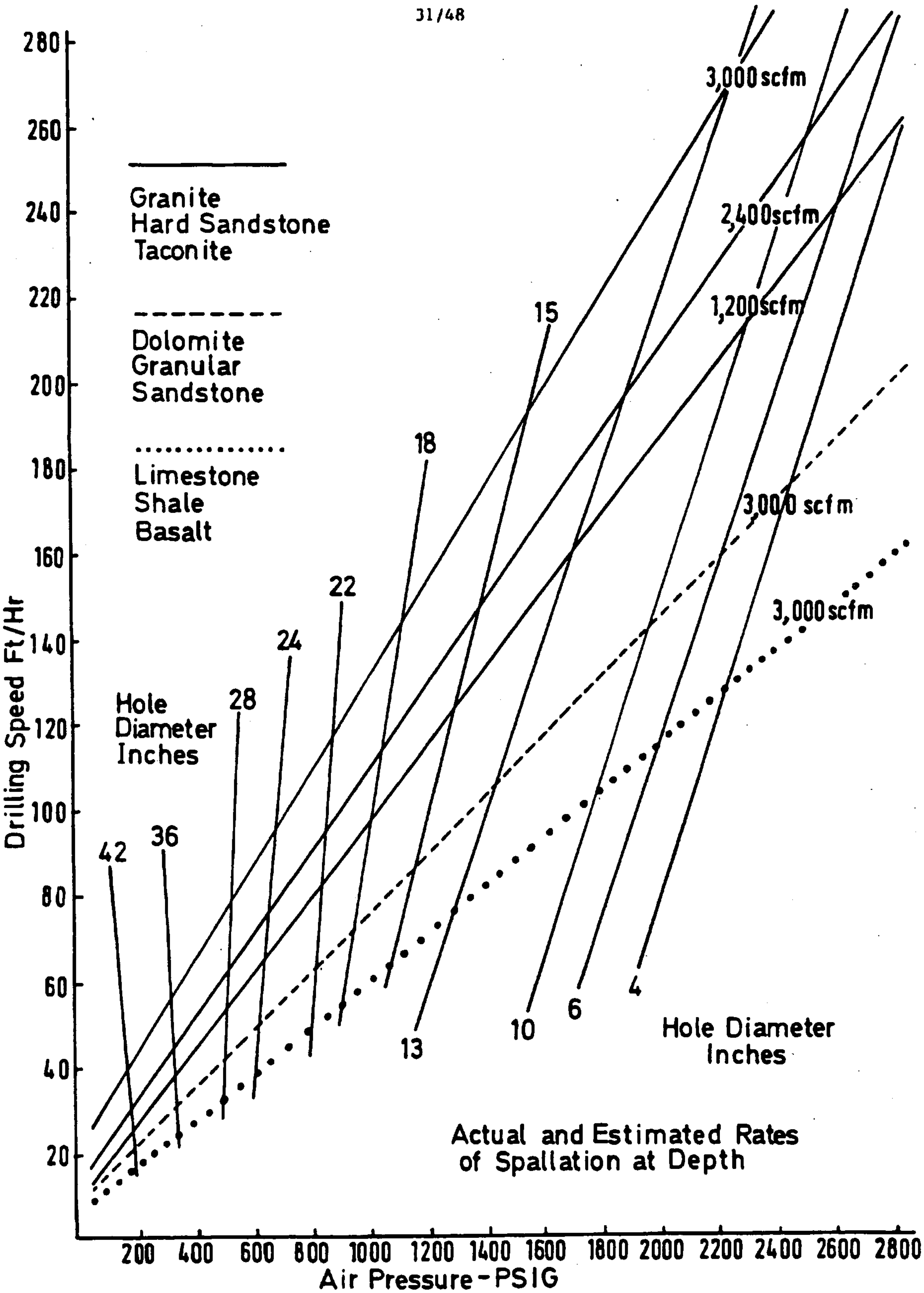

Granite
Hard Sandstone
Taconite
Dolomite
Granular
Sandstone
Limestone
Shale
Basalt
Hole Diameter Inches
42
36
28
24
22
18
15
13
10
6
4
Hole Diameter Inches
3,000 scfm
2,400 scfm
1,200 scfm
3,000 scfm
3,000 scfm
Actual and Estimated Rates of Spallation at Depth
Drilling Speed Ft/Hr
20
40
60
80
100
120
140
160
180
200
220
240
260
280
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Air Pressure - PSIG

FIG. 55

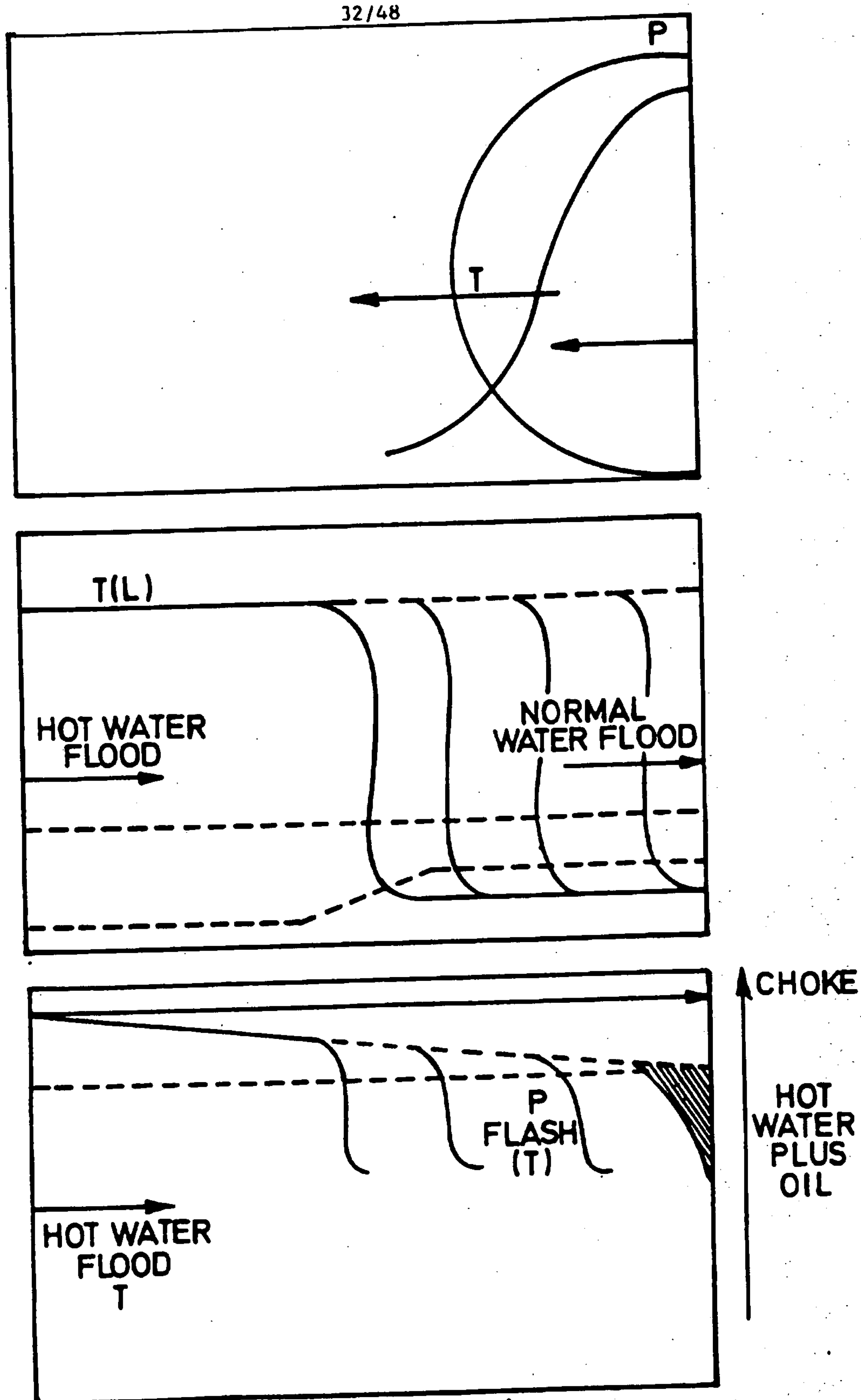

P
T
T(L)
HOT WATER FLOOD
NORMAL WATER FLOOD
CHOKE
P
FLASH
(T)
HOT WATER PLUS OIL
HOT WATER FLOOD
T

FIG. 1'

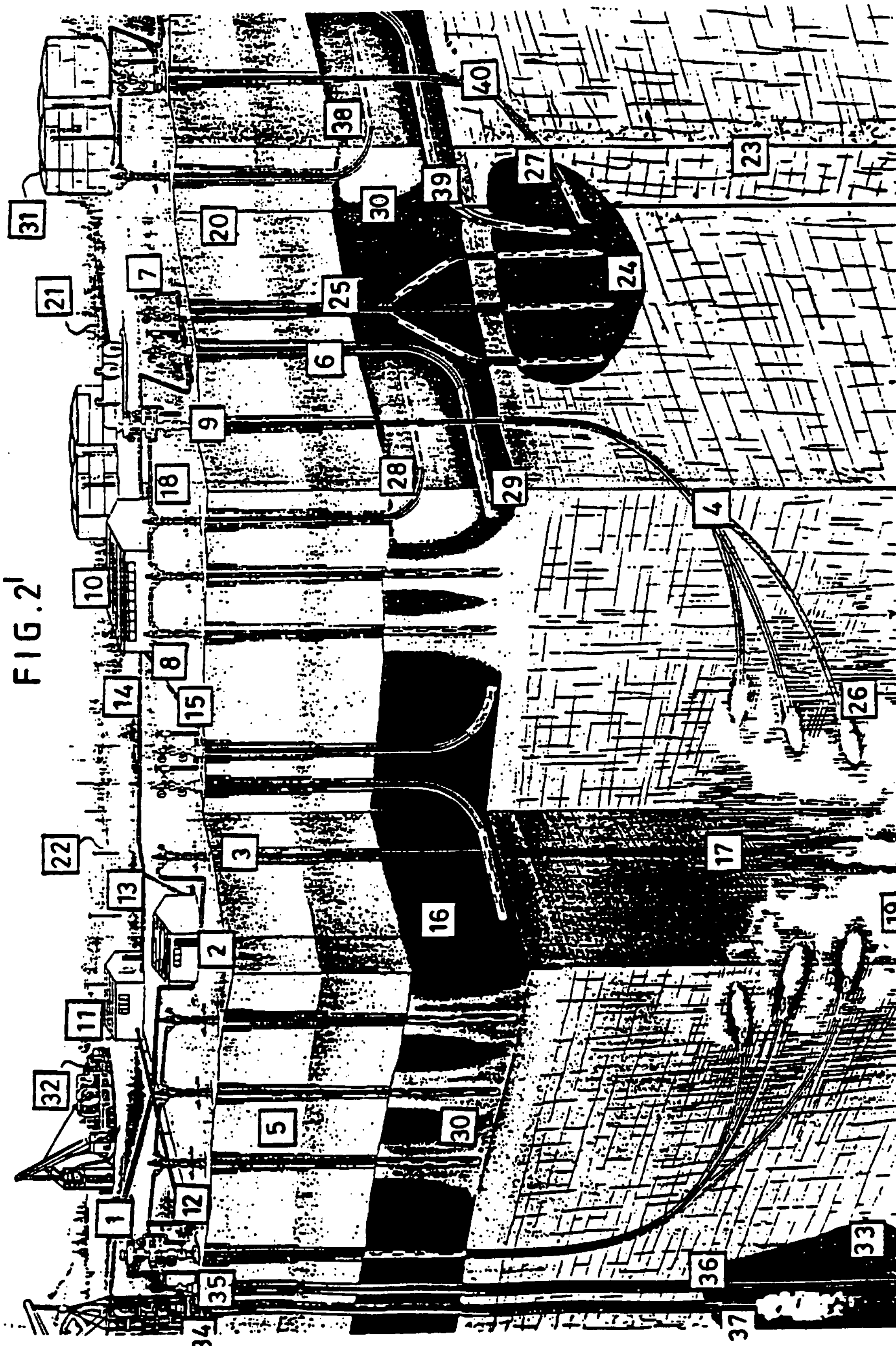

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40

FIG. 2

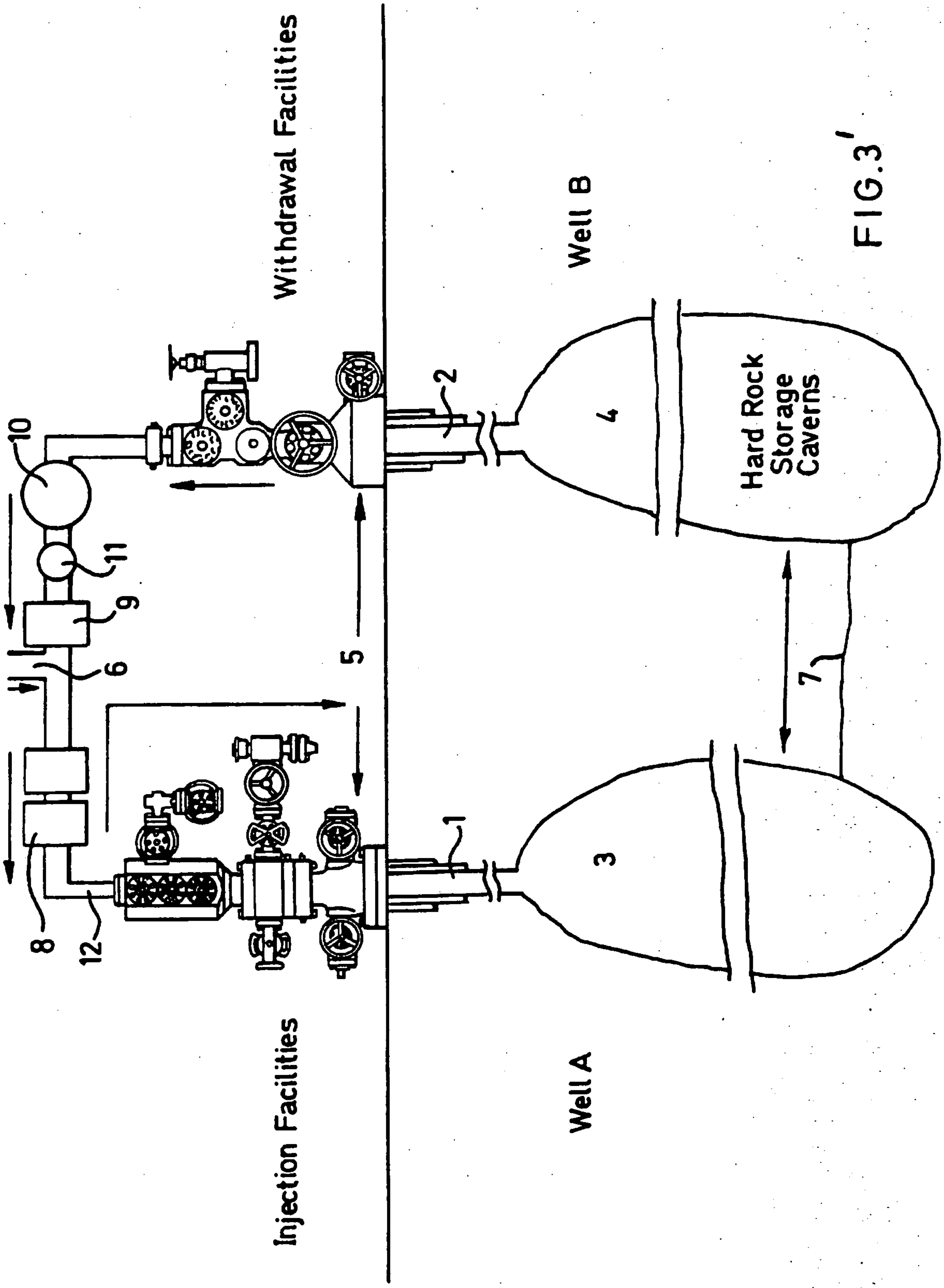

Withdrawal Facilities
Injection Facilities
Well B
Well A
Hard Rock Storage Caverns
1
2
3
4
5
6
7
8
9
10
11
12

FIG.3'

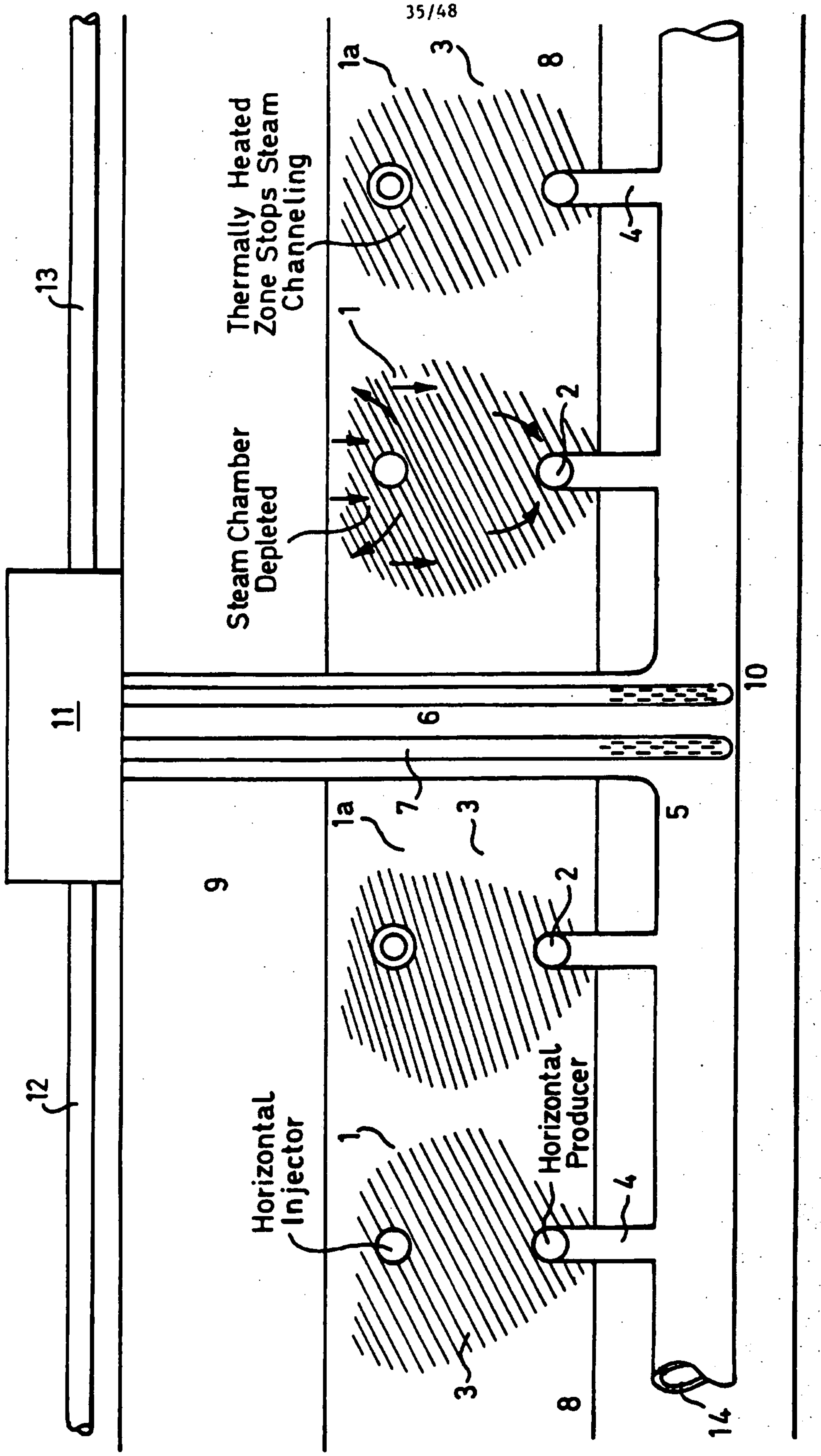

Thermally Heated Zone Stops Steam Channeling
Steam Chamber Depleted
Horizontal Injector
Horizontal Producer
11
13
12
1a
1
2
3
4
5
6
7
8
9
10
14
15

FIG. 4'

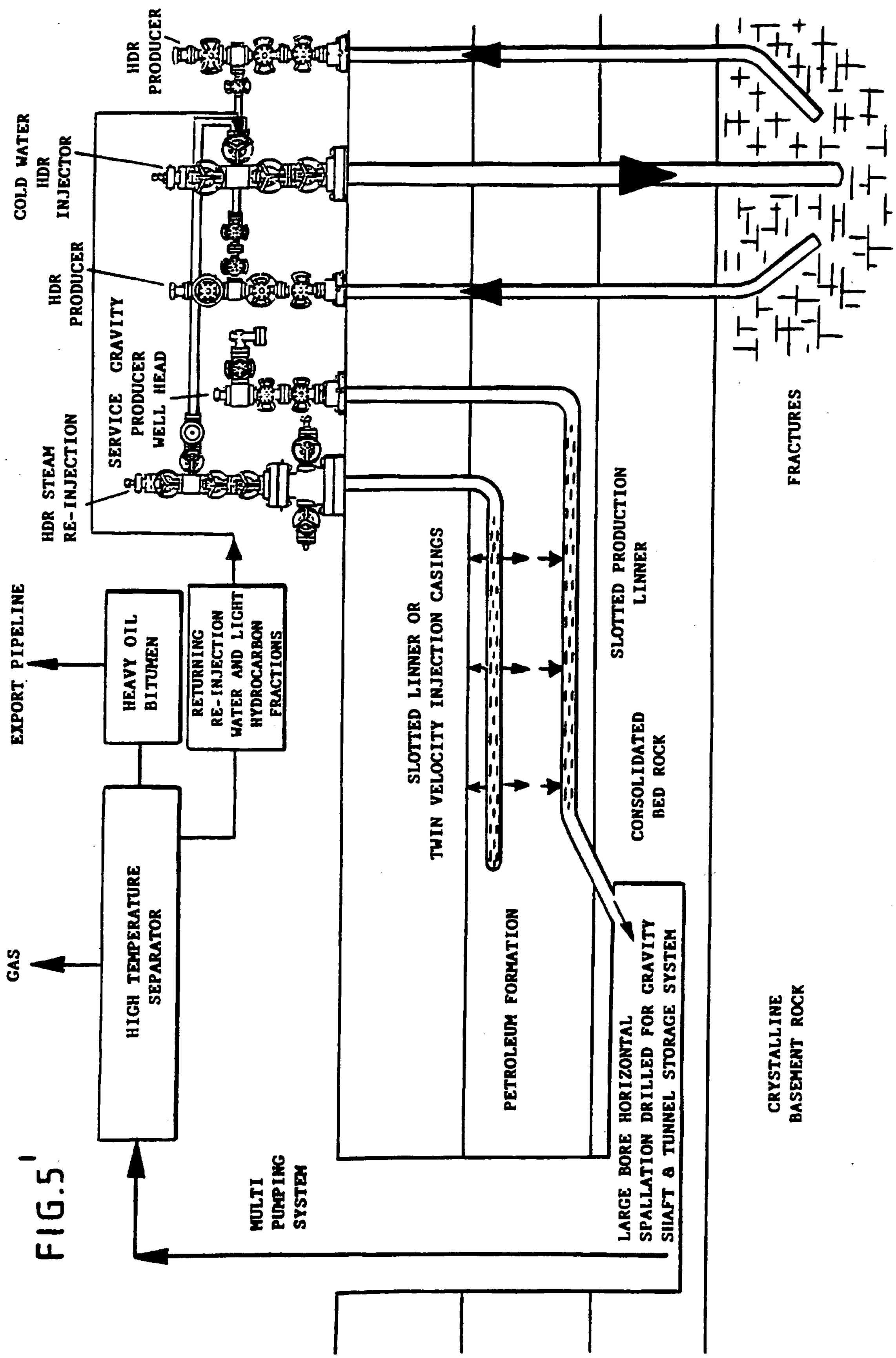

HDR PRODUCER
COLD WATER HDR INJECTOR
HDR PRODUCER
SERVICE GRAVITY PRODUCER WELL HEAD
HDR STEAM RE-INJECTION
EXPORT PIPELINE
HEAVY OIL BITUMEN
RETURNING RE-INJECTION WATER AND LIGHT HYDROCARBON FRACTIONS
GAS
HIGH TEMPERATURE SEPARATOR
MULTI PUMPING SYSTEM
SLOTTED LINNER OR TWIN VELOCITY INJECTION CASINGS
PETROLEUM FORMATION
SLOTTED PRODUCTION LINNER
CONSOLIDATED BED ROCK
LARGE BORE HORIZONTAL SPALLATION DRILLED FOR GRAVITY SHAFT & TUNNEL STORAGE SYSTEM
FRACTURES
CRYSTALLINE BASEMENT ROCK

FIG.5'

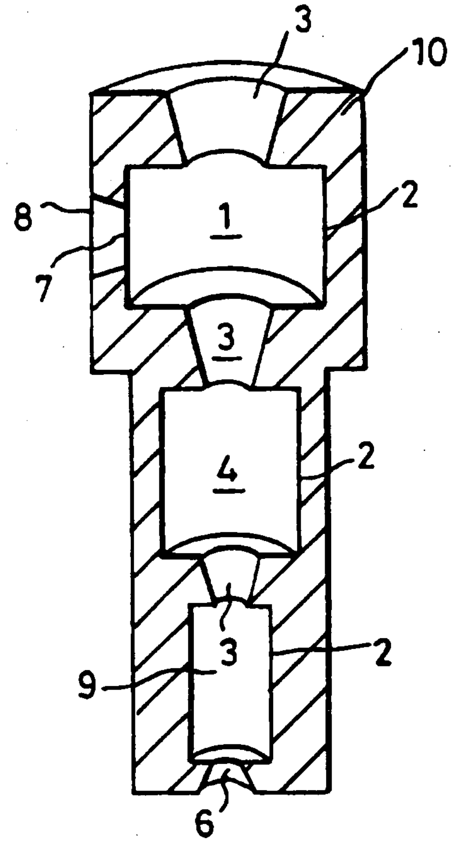


FIG.6'

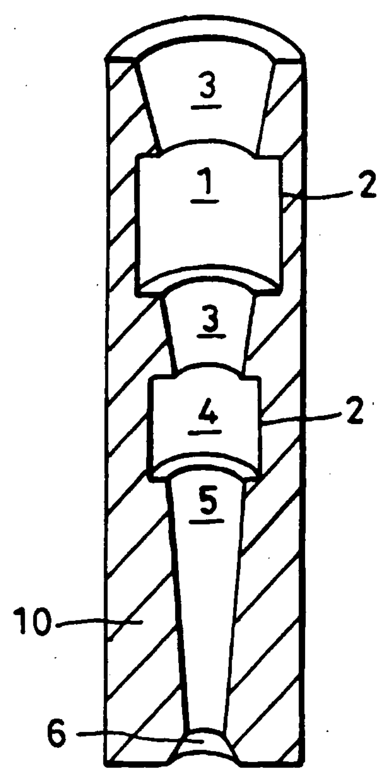


FIG.6'a

RELATIONSHIP BETWEEN STEAM QUALITY & EXPANSION PRESSURE

325 Deg. C (617 Deg. F) INJECTED WATER @ 1.740 PSI

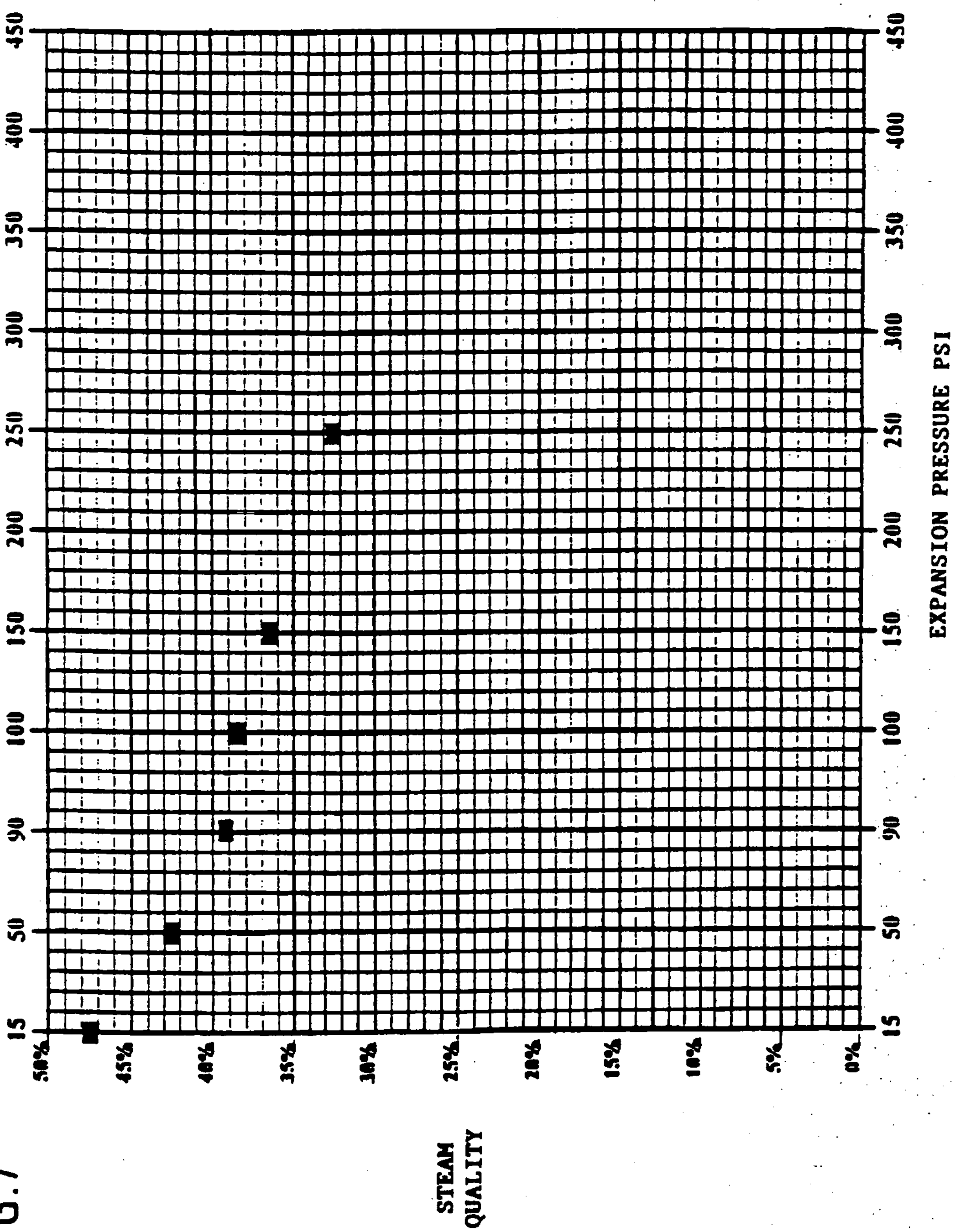


FIG.7[1]

RELATIONSHIP BETWEEN STEAM QUALITY & EXPANSION PRESSURE

325 Deg. C (617 Deg. F) INJECTED WATER @ 4,000 PSI

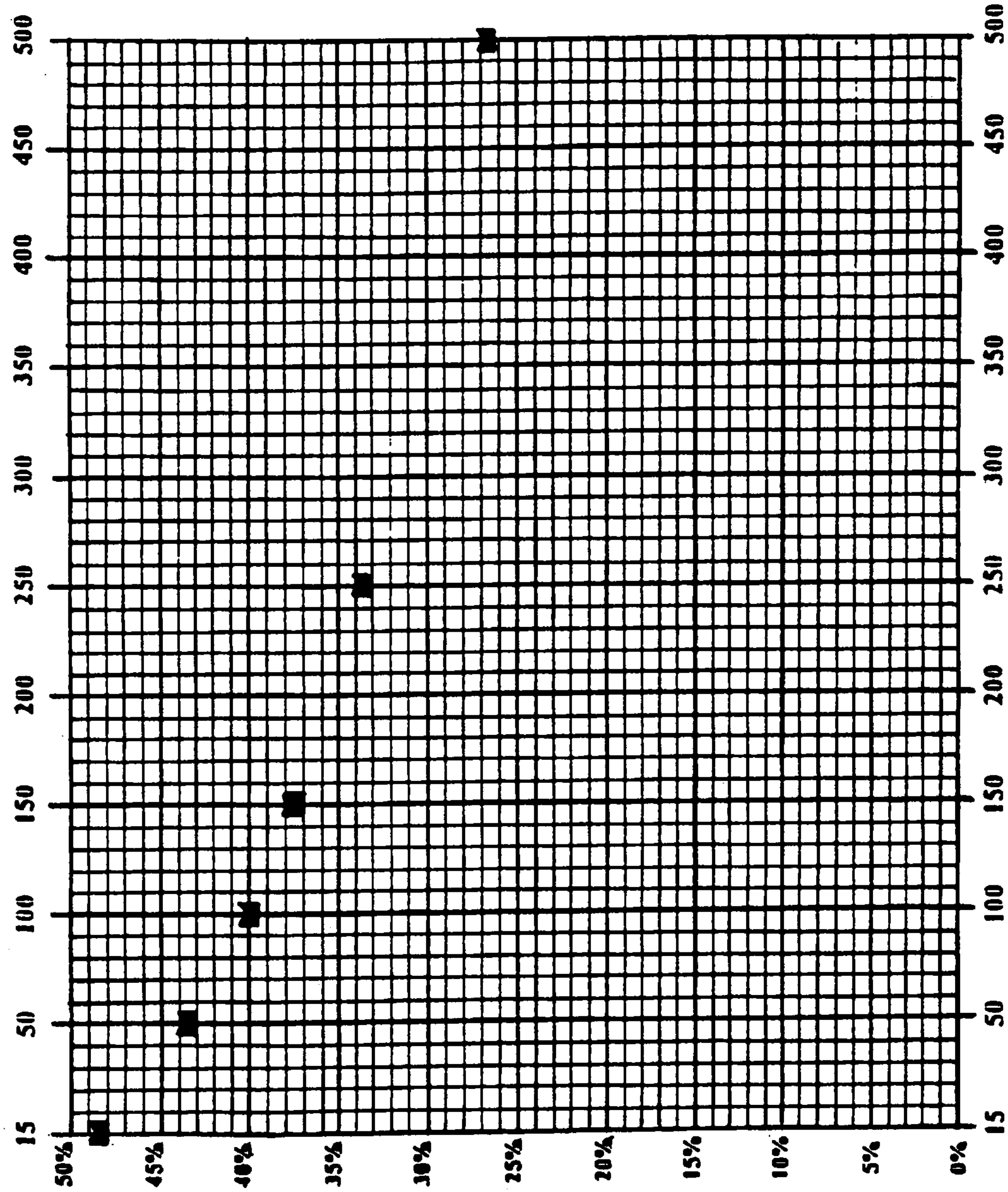


FIG.8'

FIG 9'

SUPER HOT WATER / STEAM TABLE

INJECTED WATER TEMP. DEG. C (DEG. F)	PRESSURE (PSIA)		ENTHALPY (BTU/#)			QUALITY OF STEAM (%)	SPECIFIC VOLUME (ft³/#)			MAXIMUM VOLUME EXPANSION RATIO
			INJECTION	EXPANDED			INJECTION	EXPANDED		
	INJECTED	EXPAND	WATER	WATER	STEAM		WATER	WATER	STEAM	
325 (617)	4000	500	655.8	449.5	1205.3	27.3	.02426	.01975	0.9298	10.9
325 (617)	4000	250	655.8	376.2	1202.1	33.9	.02426	.01865	1.7683	25.0
325 (617)	3500	400	652.7	424.2	1205.5	29.2	.02431	.01935	1.1584	15.2
325 (617)	3500	200	652.7	355.6	1199.3	35.2	.02431	.01839	2.286	33.6
325 (617)	1740	250	641.8	376.2	1202.1	32.2	.02448	.01865	1.7683	23.8
325 (617)	1740	150	641.8	330.8	1194.9	36.0	.02448	.01808	3.034	45.1
300 (572)	3000	250	587.0	376.2	1202.1	25.5	.02232	.01865	1.7683	20.8
300 (572)	2500	500	584.4	449.5	1205.3	17.8	.02237	.01975	0.9298	8.1
300 (572)	2500	250	584.4	376.2	1202.1	25.2	.02237	.01865	1.7683	20.5
300 (572)	2000	500	581.8	449.5	1205.3	17.5	.02241	.01975	0.9298	8.0
300 (572)	2000	200	581.8	355.6	1199.3	26.8	.02241	.01839	2.286	27.9
280 (536)	2000	250	536.2	376.2	1202.1	19.4	.02125	.01865	1.7683	16.9
280 (536)	1750	200	535.1	355.6	1199.3	21.3	.02127	.01839	2.2860	23.6
270 (518)	800	100	509.7	298.6	1187.8	23.7	.02134	.01774	4.4260	49.8
230 (445)	400	50	424.2	250.2	1174.4	18.8	.01934	.01727	8.524	83.6
180 (359)	150	15	330.8	181.2	1150.9	15.4	.01809	.01672	26.8	228.9
325 (617)	4000	150	655.8	330.8	1194.8	37.6	.02426	.01808	3.034	47.1
325 (617)	4000	100	655.8	298.6	1187.8	40.2	.02426	.01774	4.426	73.2
325 (617)	1740	100	641.8	298.6	1187.8	38.6	.02448	.01774	4.426	70.2
325 (617)	3500	100	652.7	298.6	1187.8	39.8	.02431	.01774	4.426	72.9
325 (617)	1740	90	641.8	290.5	1185.9	39.2	.02448	.01766	4.898	78.9
325 (617)	4000	50	655.8	250.2	1174.4	43.9	.02426	.01727	8.524	153.6
325 (617)	4000	20	655.8	196.3	1156.4	47.9	.02426	.01683	20.09	394.6
325 (617)	4000	15	655.8	181.2	1150.9	48.9	.02426	.01672	26.8	538.3
230 (445)	400	15	424.2	181.2	1150.9	25.1	.01934	.01672	26.8	348.5
325 (617)	1740	50	641.8	250.2	1174.4	42.4	.02448	.01727	8.524	147.9
325 (617)	1740	15	641.8	181.2	1150.9	47.5	.02448	.01672	26.8	520.4
325 (617)	2000	20	643.0	196.3	1156.4	46.5	.02446	.01683	20.09	382.5
280 (536)	950	15	509.7	196.3	1150.9	32.8	.02125	.01839	26.80	414.6

FIG.10'

SUPER HOT WATER / STEAM TABLE												
INJECTED WATER TEMP.	EXPANDED GEOFLUID TEMP.	PRESSURE (PSIA)		ENTHALPY (BTU/#)			QUALITY OF STEAM	SPECIFIC VOLUME (ft/#)			MAXIMUM VOLUME EXPANSION
				INJECTION	EXPANDED			INJECTION	EXPANDED		
DEG. C (DEG. F)	DEG. C (DEG. F)	INJECTED	EXPAND	WATER	WATER	STEAM	(%)	WATER	WATER	STEAM	RATIO
355 (670)	252 (486)	3,000	600	738.4	471.7	1204.1	36.4	0.02882	0.020300	0.7702	10.95
355 (670)	242 (467)	3,000	500	738.4	449.5	1205.3	38.2	0.02882	0.197480	0.9283	13.60
355 (670)	229 (445)	3,000	400	738.4	424.2	1205.5	40.2	0.02882	0.019340	1.1620	17.70
355 (670)	214 (417)	4,000	300	746.9	394.1	1203.9	43.6	0.02882	0.018896	1.5442	25.10
360 (680)	270 (518)	3,000	600	738.4	509.7	1199.3	36.9	0.03032	0.020870	0.5691	7.90
360 (680)	222 (432)	3,000	350	738.4	409.9	1204.9	44.0	0.03032	0.019124	1.3267	21.00
360 (680)	194 (382)	3,000	200	738.4	555.6	1194.3	47.9	0.03032	0.018387	2.2890	38.70
360 (680)	164 (328)	3,000	100	759.6	299.4	1188.0	51.8	0.03032	0.017736	4.4340	80.10
360 (680)	153 (308)	4,000	75	768.9	277.6	1182.4	54.3	0.03032	0.017524	5.8180	109.80
360 (680)	138 (281)	4,000	50	768.9	250.2	1174.4	56.1	0.03032	0.017269	8.5180	165.60
360 (680)	138 (281)	5,000	50	778.2	250.2	1174.4	57.1	0.03032	0.017269	8.5180	168.40
368 (694)	284.9 (544.8)	3,500	1,000	807.3	542.4	1192.4	40.8	0.0340	0.021590	0.4459	6.22
368 (694)	261.8 (503.2)	3,500	700	807.3	491.5	1202.0	44.4	0.0340	0.020518	0.6558	13.06
368 (694)	252.4 (486.3)	3,500	600	807.3	471.7	1204.1	45.8	0.0340	0.020130	0.7702	17.8
368 (694)	241.7 (467.1)	3,500	500	807.3	449.5	1205.3	47.3	0.0340	0.019748	0.9283	25.7
368 (694)	220.3 (444.7)	3,500	400	807.3	424.2	1205.5	49.0	0.0340	0.019340	1.1620	40.0
368 (694)	214.1 (417.4)	3,000	300	797.8	394.1	1203.9	49.9	0.0338	0.018896	1.5442	70.8
368 (694)	164.4 (327.9)	3,000	100	797.8	298.6	1187.8	56.1	0.0338	0.017736	4.434	58.2
385 (725)	252.4 (486.3)	3,500	600	~ 1020	471.7	1204.1	74.9	0.0750	0.020130	0.7702	8.0
400 (752)	241.7 (467.1)	3,500	500	~ 1125	449.5	1205.5	89.4	0.1050	0.019748	0.9283	8.3
410 (770)	241.7 (467.1)	3,500	500	~ 1170	449.5	1205.3	95.3	0.1250	0.019748	0.9283	6.9

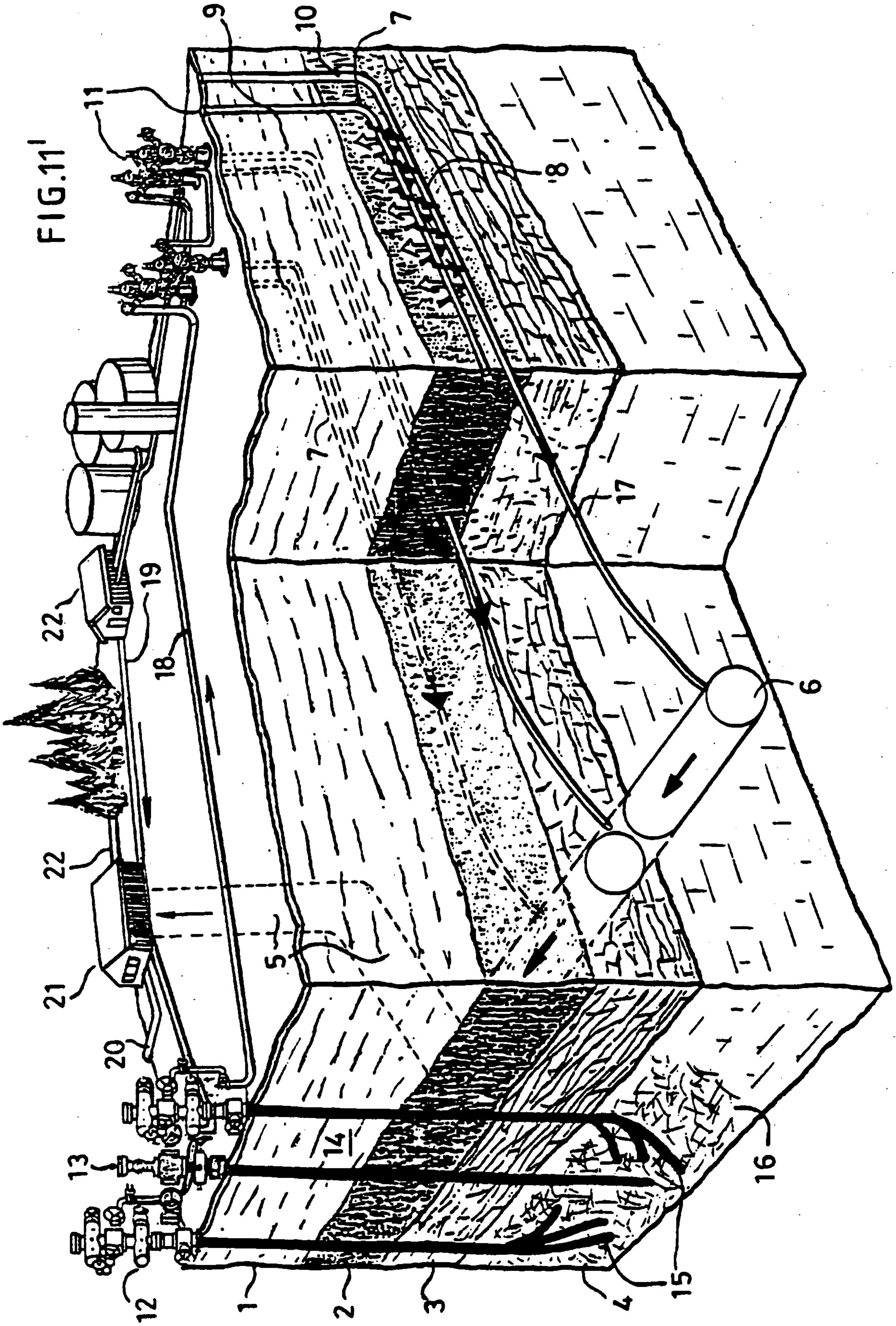


FIG.11'

FIG.12'

RELATIONSHIP BETWEEN STEAM QUALITY & GEOFLUID EXPANSION PRESSURE AT THE HDR PRODUCTION WELLHEAD

380 Deg. C (716 Deg. F) INJECTED @ 3,204 PSI (Critical Pressure)

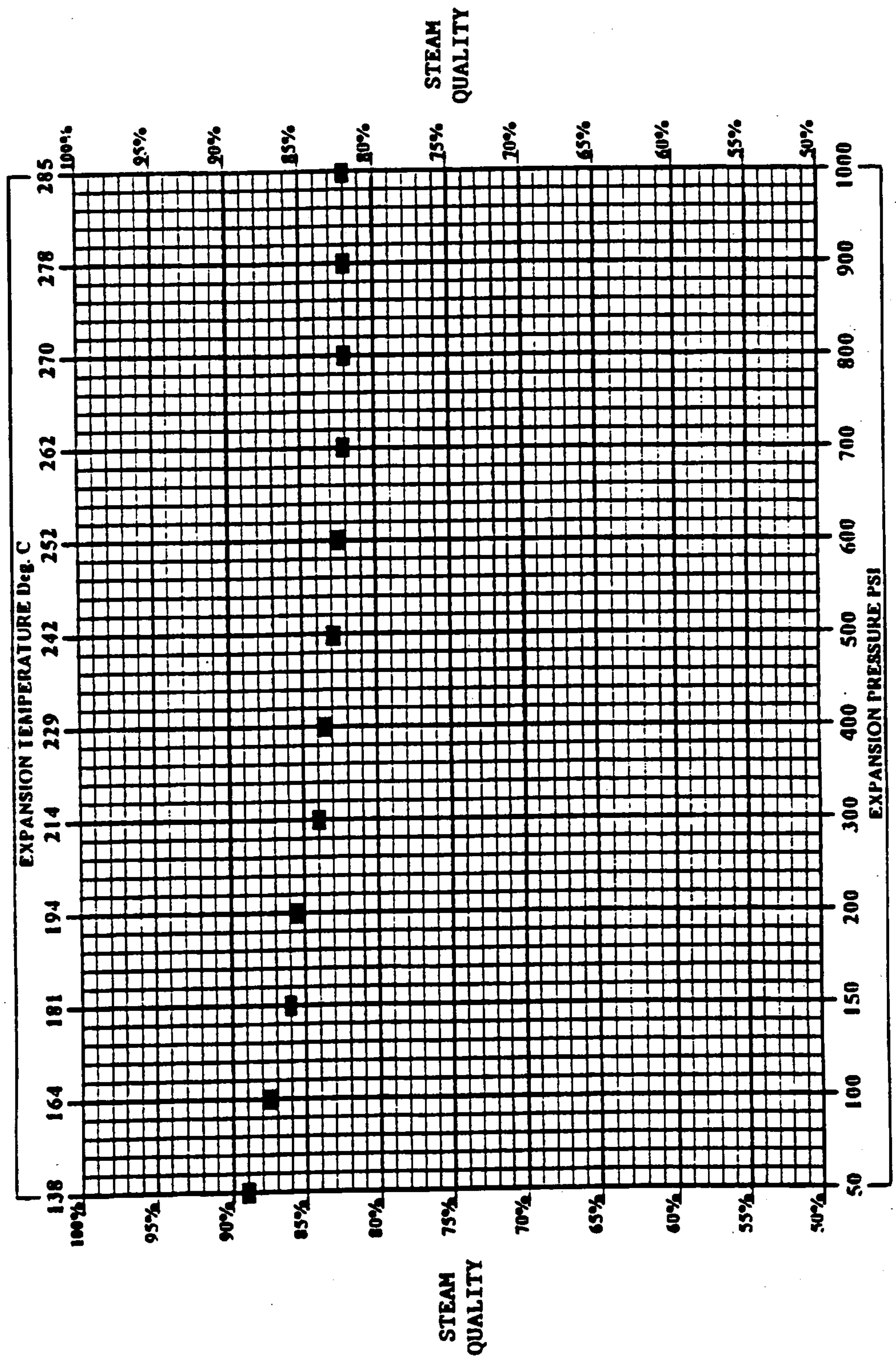


FIG.13'

RELATIONSHIP BETWEEN STEAM QUALITY
&
GEOFLUID EXPANSION PRESSURE AT THE HDR PRODUCTION WELLHEAD

Super Critical Temperature of 380 Deg. C (716 Deg. F) Injected @ 3,204 PSI (Critical Pressure)

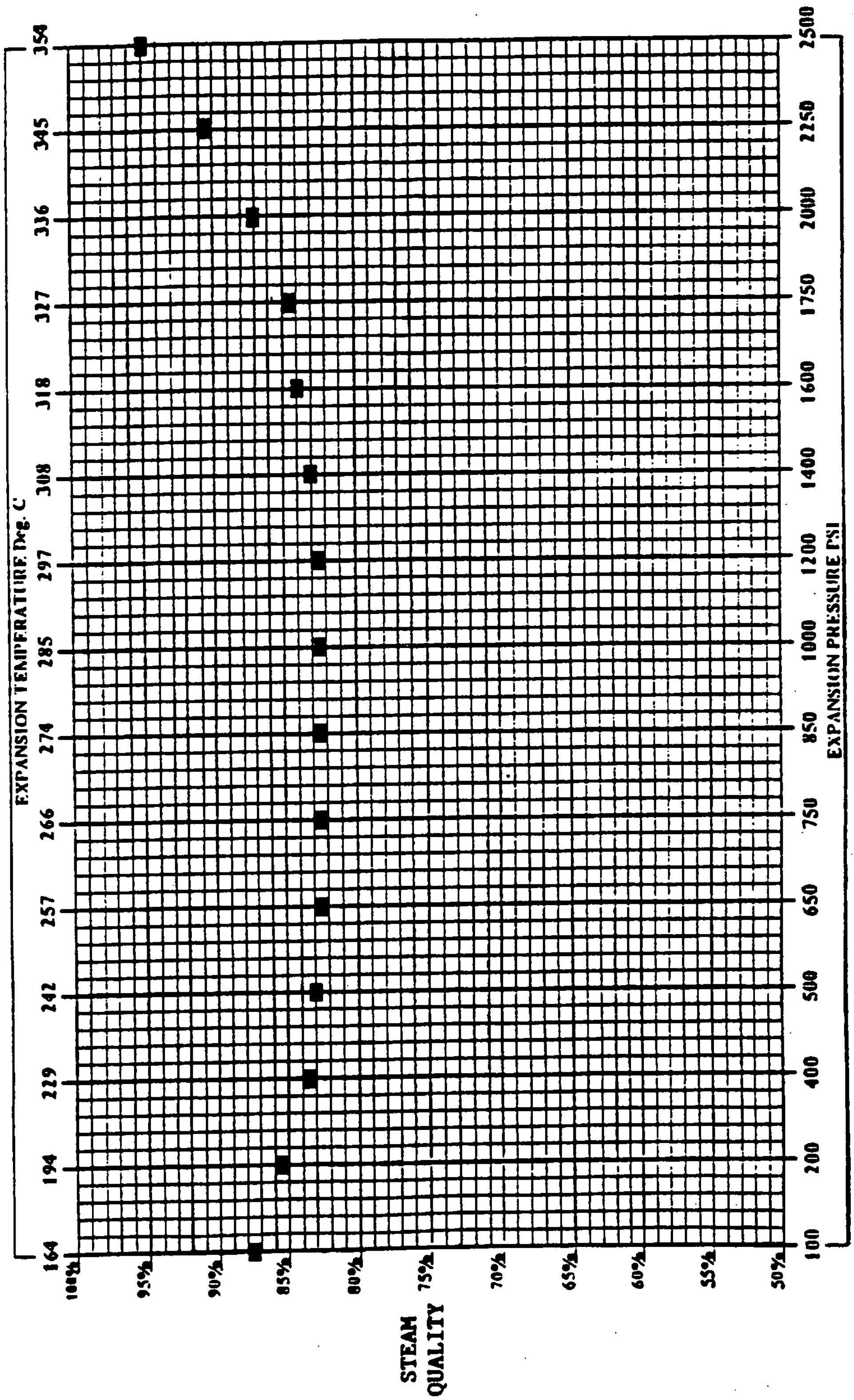
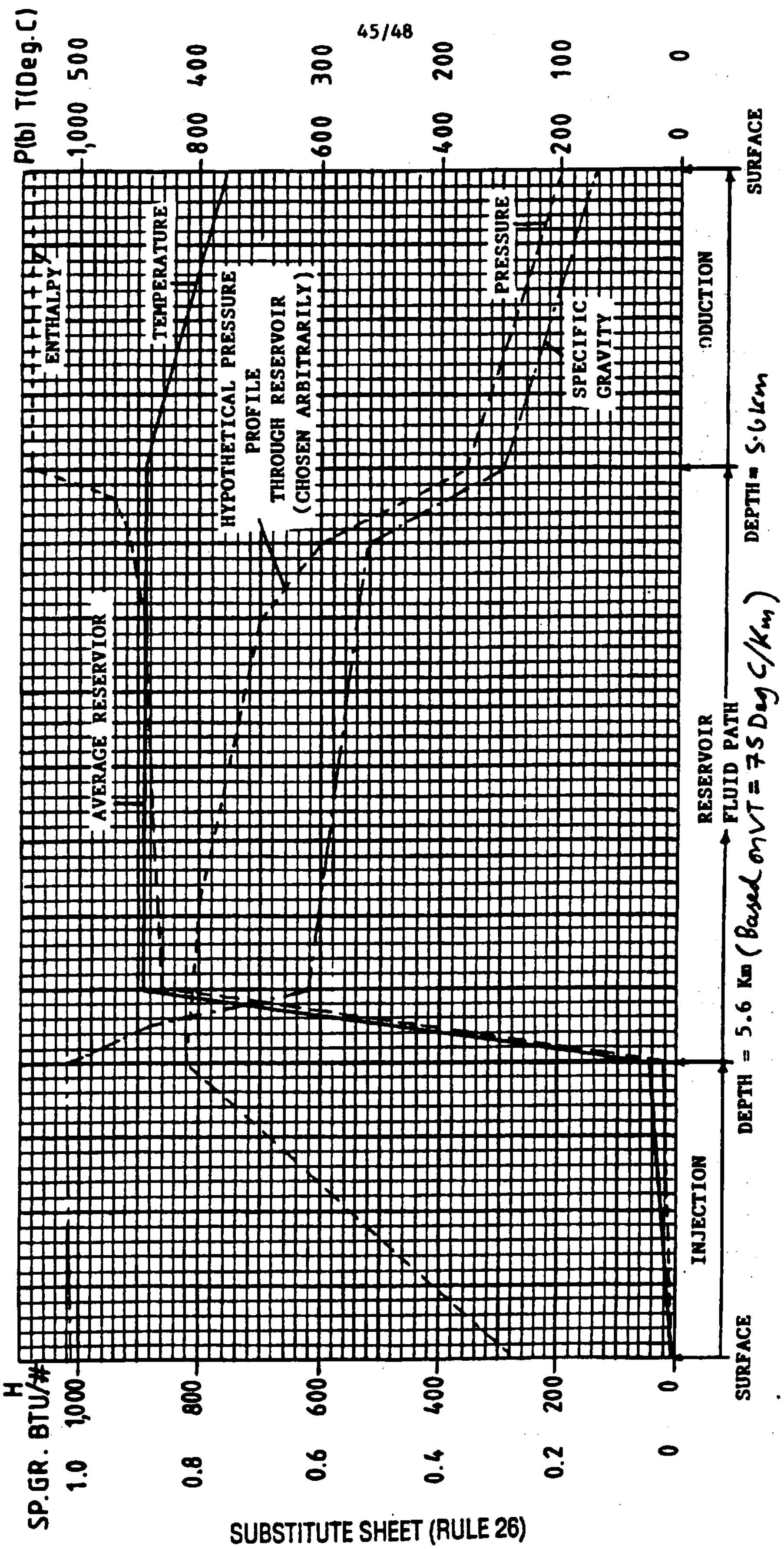


FIG.14'


P(b) T(Deg.C)
0 200 400 600 800 1,000
0 100 200 300 400 500
H
SP.GR. BTU/#
0 200 400 600 800 1,000
0 0.2 0.4 0.6 0.8 1.0
ENTHALPY
TEMPERATURE
HYPOTHETICAL PRESSURE PROFILE THROUGH RESERVOIR (CHOSEN ARBITRARILY)
PRESSURE
SPECIFIC GRAVITY
AVERAGE RESERVOIR
SURFACE
INJECTION
DEPTH = 5.6 Km (Based on VT = 75 Deg C/Km)
RESERVOIR FLUID PATH
DEPTH = 5.6 Km
SURFACE

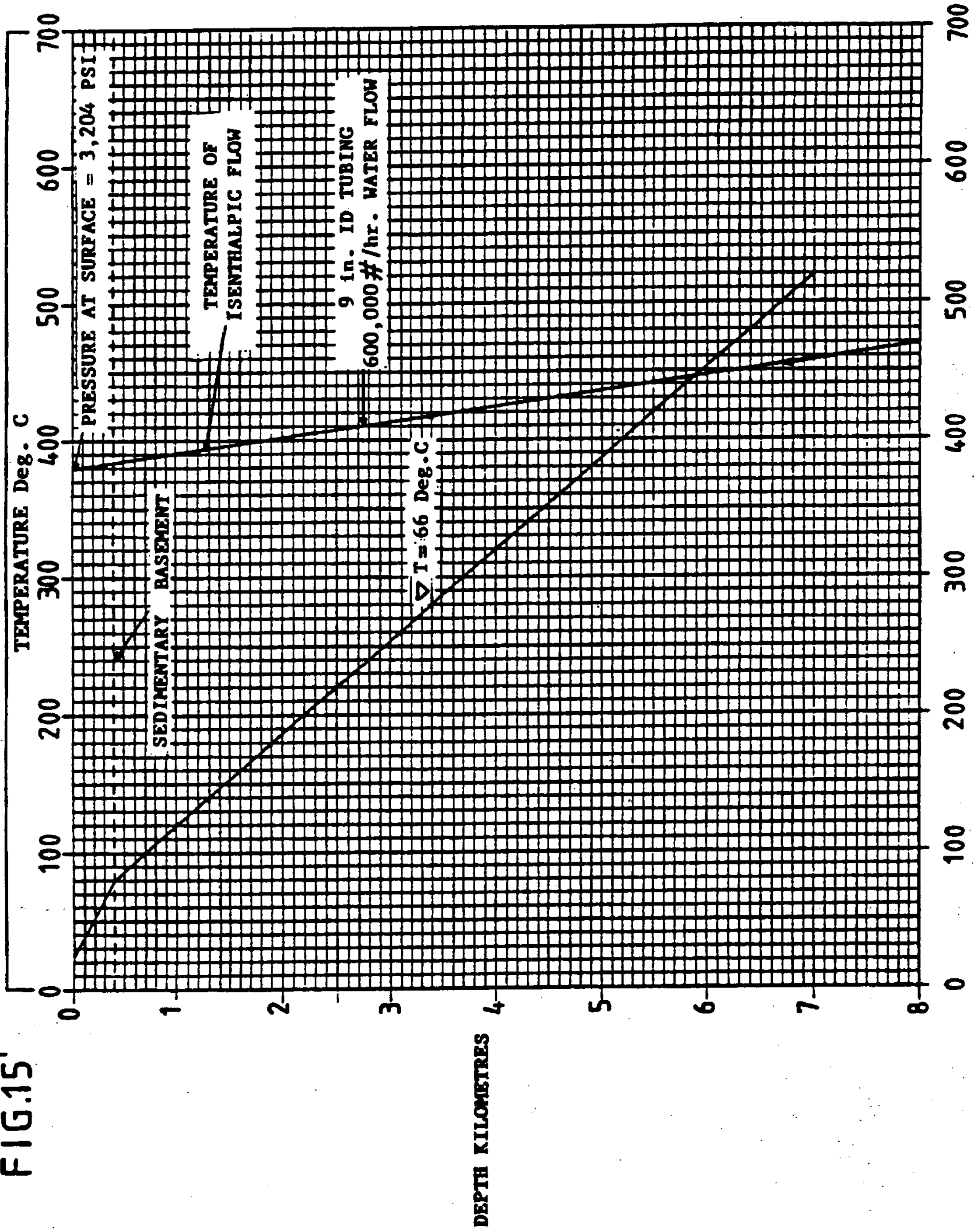

TEMPERATURE Deg. C
PRESSURE AT SURFACE = 3,204 PSI
TEMPERATURE OF
ISENTHALPIC FLOW
9 in. ID TUBING
600,000#/hr. WATER FLOW
SEDIMENTARY BASEMENT
T = 66 Deg.C
0
100
200
300
400
500
600
700
0
1
2
3
4
5
6
7
8
DEPTH KILOMETRES

FIG.15'

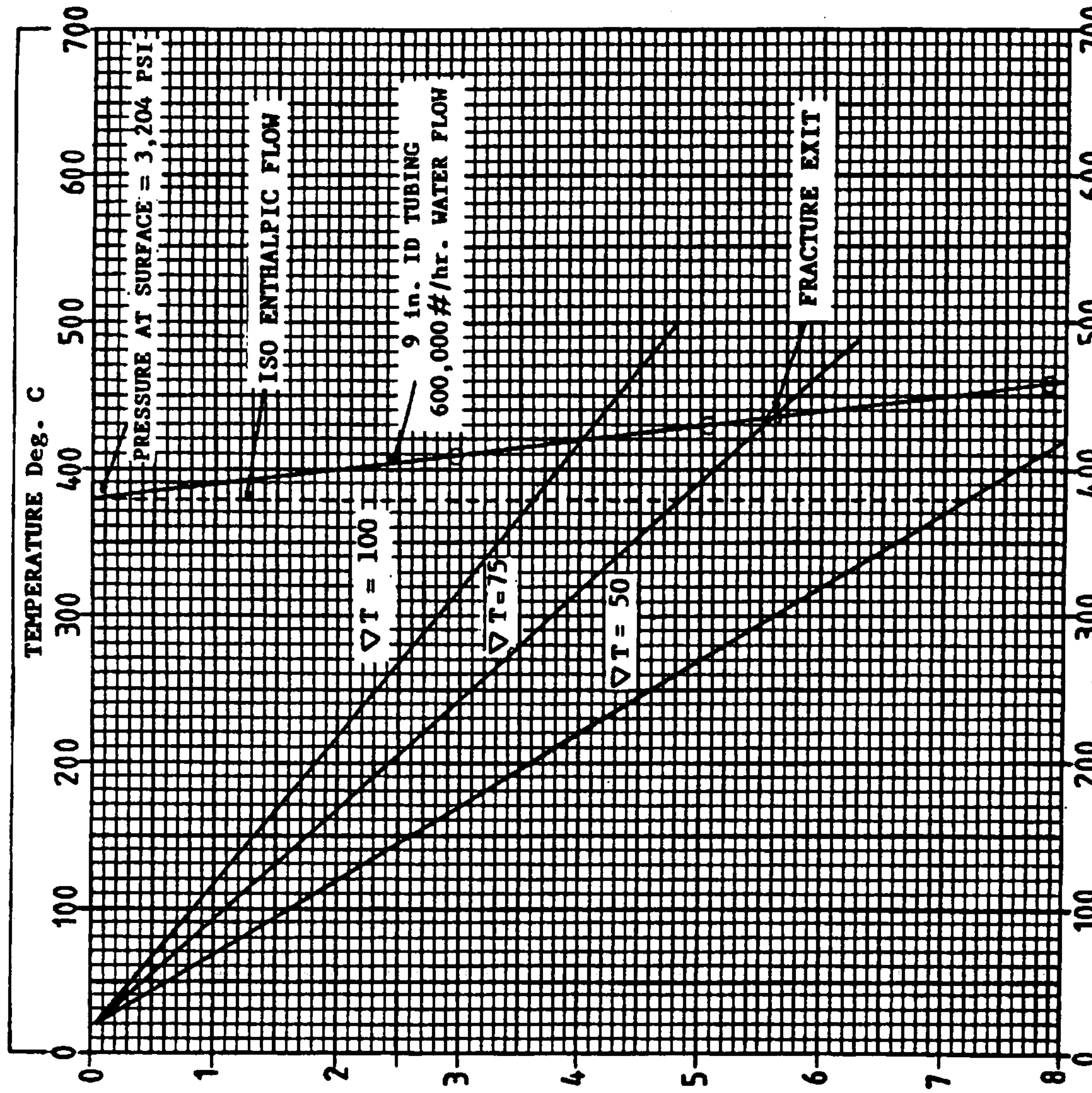

TEMPERATURE Deg. C
PRESSURE AT SURFACE = 3,204 PSI
ISO ENTHALPIC FLOW
9 in. ID TUBING
600,000 #/hr. WATER FLOW
FRACTURE EXIT
∇T = 100
∇T = 75
∇T = 50
0
100
200
300
400
500
600
700
0
1
2
3
4
5
6
7
8
DEPTH KILOMETRES

FIG.16'

SPECIFIC GRAVITY OF WATER vs TEMPERATURE & PRESSURE

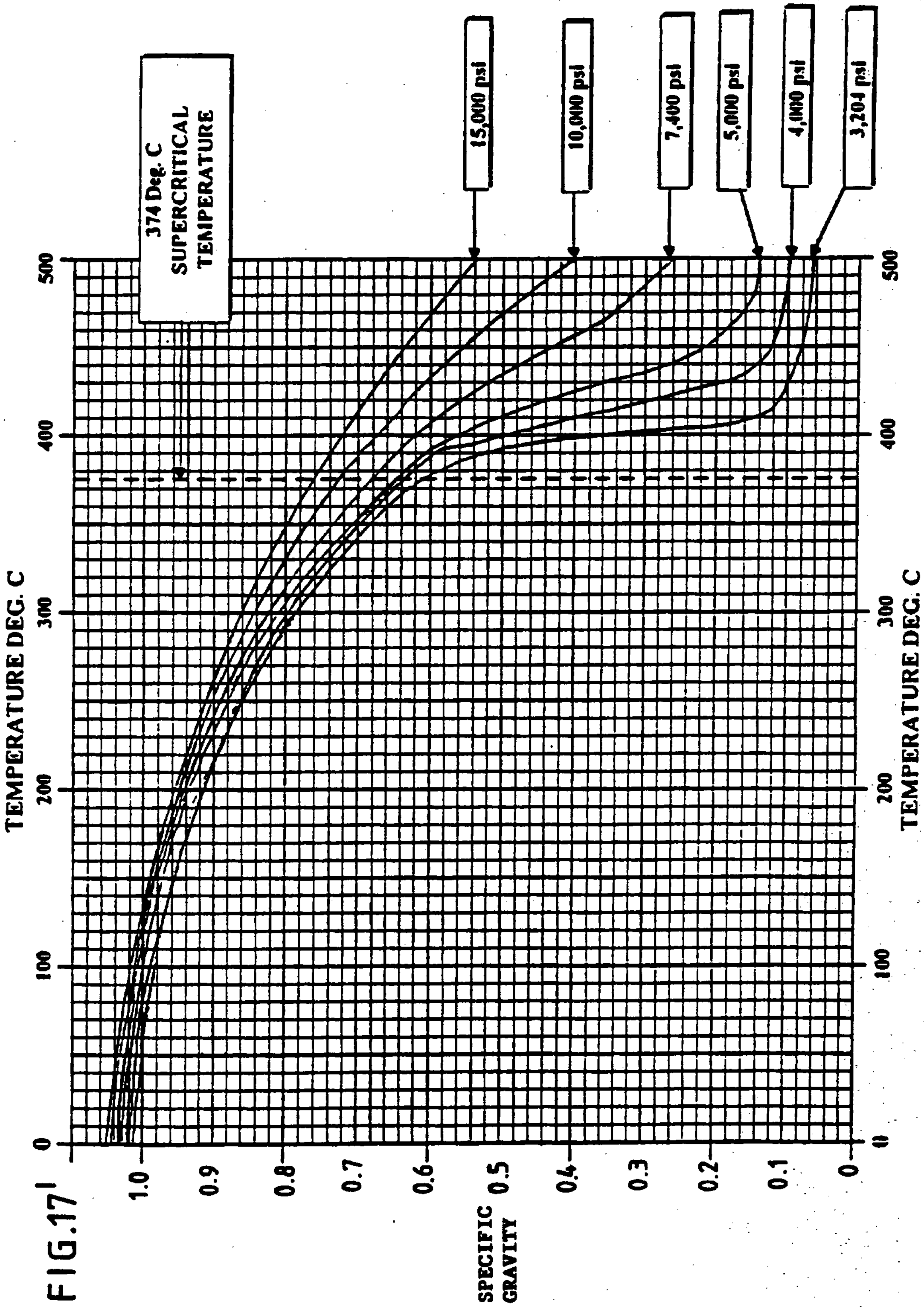


FIG.17

PCT

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9416668.3	17 August 1994 (17.08.94)	GB
9416738.4	18 August 1994 (18.08.94)	GB
9417100.6	24 August 1994 (24.08.94)	GB
9417436.4	30 August 1994 (30.08.94)	GB
9422900.2	14 November 1994 (14.11.94)	GB

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(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, UG, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ, UG).

Published

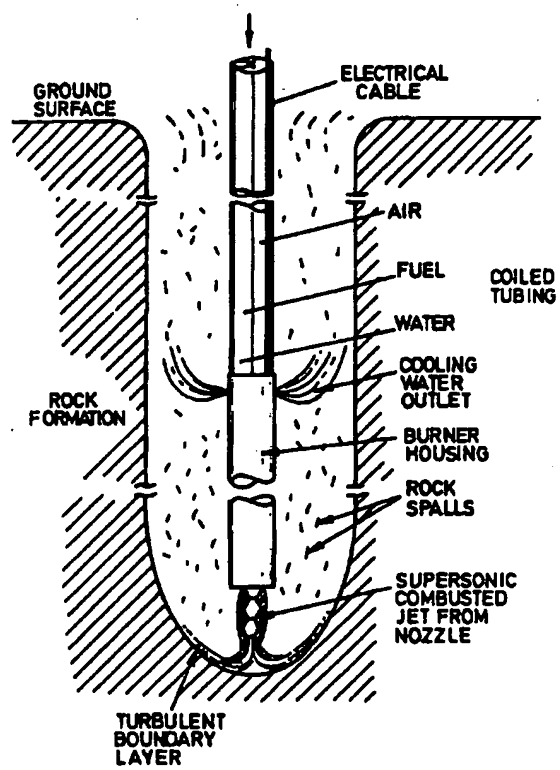
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(88) Date of publication of the international search report: 9 May 1996 (09.05.96)

(54) Title: IMPROVEMENTS IN OR RELATING TO DRILLING WITH GAS LIQUID SWIRL GENERATOR HYDROCYCLONE SEPARATION COMBUSTION THERMAL JET SPALLATION

(57) Abstract

A high velocity 3 phase mixture is pumped down a drill string to a vortex swirl generator/hydrocyclone for 2 phase separation flow into a twin vortex combustion chamber manifold that swirls the air in and around the fuel and water mixture droplets (atomise) producing instant exothermic heat of combustion thereby producing a super-critical thermal spallation jet flow; with surface control of the water to fuel (kerosene) content allows temperature control between 400 °C and 1,800 °C with additional abrasive particles if required, axial pulse jets are also optional for further erosion to the rock face, allowing the spalling of all rocks with high strength to low ductile transformation temperatures. The spallation drilling system makes possible drilling of well bores to allow the use of steam drive and alternating steam injection within oil reservoirs and electrical power generation which are able to use super-critical HDR principles with water temperatures above super-critical 374 °C and critical pressure of 3,204 psi for expansion back to lower pressure with high quality steam.



INTERNATIONAL SEARCH REPORT

Inte[rnatio]nal Application No
PCT/GB 95/01709

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 E21B7/14 E21B21/00 E21B43/29

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A,3 792 741 (HOPLER) 19 February 1974 see abstract; figures ---	1
A	US,A,2 896 914 (RYAN) 28 July 1959 see claim 1; figures ---	1
A	GB,A,1 056 628 (FLETCHER) 27 September 1965 see claim 1; figures ---	1
A	US,A,3 344 870 (MORRIS) 3 October 1967 see abstract; figures ---	1
A	US,A,3 463 249 (BROWNING) 26 August 1969 see abstract; figures ---	1
A	US,A,3 467 206 (ACHESON) 16 September 1969 see abstract; figures ---	1
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
29 November 1995	27.03.96

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	WEIAND T.

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A,3 475 055 (SNEDDEN) 28 October 1969 see abstract; figures ---	1
A	US,A,3 476 194 (BROWNING) 4 November 1969 see abstract; figures ---	1
A	US,A,3 835 937 (HOKAO) 17 September 1974 see abstract; figures ---	1
A	US,A,4 066 137 (FRANKLE) 3 January 1978 see abstract; figures ---	1
P,A	WO,A,94 21889 (NORTH) 29 September 1994 cited in the application see abstract; figures -----	1

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International application No.

PCT/GB95/01709

INTERNATIONAL SEARCH REPORT

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See B-sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searches without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1,3-6,10-12,15-22,24,25,44,55

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

1. Claims 1,3,4.5.6.10.11,12,15-22,24,25,44,55: Combustion jet spallation drilling in combination with downhole separation
2. Claims 2,7,14,28.39.49,54,48: vortex chamber
3. Claims 8,9.56: orientation control
4. Claim 13: coiled tubing
5. Claim 23.46.47,50: spallation drilling with jet nozzles
6. Claim 26: controlling borehole size with water
7. Claim 27,41: open cracks
8. Claim 29: controlling
9. Claim 30,32: downhole storage
10. Claim 31: acoustic coupling
11. Claim 33.34.35: fuel and water
12. Claim 36.37,55: separation
13. Claim 38: downhole valve
14. Claim 42.43,45.51,52,57,58,63: controlling production pressure
15. Claim 53: energy reclamation
16. Claim 59: storage caverns
17. Claim 60: large well bores
18. Claim 61: concrete
19. Claim 62: waste disposal

Reasons:

Rule 13 PCT requires for a group of inventions to be unified by a common inventive concept. involving one or more corresponding special technical features. Special technical features are those which define a contribution which each of the claimed inventions considered as a whole makes over the prior art.
The special technical feature of claim 1 is the downhole separation (centrifuge), as combustion jet spallation drilling is known from for example document US-A-3792741.
Accordingly all claims not disclosing this special technical feature are deprived from unity of invention.
A search has been carried out only for item 1.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 95/01709

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A-3792741	19-02-74	AU-B-	5016872	20-06-74
		CA-A-	972345	05-08-75
US-A-2896914	28-07-59	NONE		
GB-A-1056628		NONE		
US-A-3344870	03-10-67	NONE		
US-A-3463249	26-08-69	DE-A-	1918964	20-11-69
		FR-A-	2007166	02-01-70
		GB-A-	1224453	10-03-71
US-A-3467206	16-09-69	NONE		
US-A-3475055	28-10-69	NONE		
US-A-3476194	04-11-69	NONE		
US-A-3835937	17-09-74	NONE		
US-A-4066137	03-01-78	NONE		
WO-A-9421889	29-09-94	AU-B-	6214794	11-10-94
		CA-A-	2158637	29-09-94